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BUILDING ENERGY RESEARCH WORKSHOP

PROCEEDINGS

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May 17, 1983

LETTER OF TRANSMITTAL

To All Members of the Committee on Science and Technology:

I am herewith transmitting the proceedings of the Building Energy Research Workshop sponsored by the Committee on Science and Technology at the Carmel Valley Inn, January 12-14, 1983. The Workshop was co-sponsored by the U.S. Department of Energy, the Electric Power Research Institute, the Gas Research Institute, the National Association of Home Builders Research Foundation, the American Institute of Architects and the American Society of Heating, Refrigeration and Air Conditioning Engineers. Its objective was to formulate a national agenda for research in energy efficiency and solar energy related to buildings.

Fifty six participants, representing the building industry, its trade associations, the national laboratories, public interest groups, private sector research organizations and federal agencies, were invited by the co-sponsors to attend the workshop. They worked together in panels oriented around specific research areas such as materials, storage and envelope subsystems; windows, daylighting and passive solar; ventilation, infiltration, moisture control and indoor air quality; whole building performance research; and technology transfer and disincentives to energy efficiency.

The proceedings were prepared by Science Applications, Inc. under contract with the Electric Power Research Institute.

The workshop was a landmark event in the development of a consensus among government, industry and national laboratory officials on the needs for further research and development in the building energy use area. The Committee has already used the results of the workshop in its FY 1984 budget recommendations.

Any comments from Members of the Committee, other Members of Congress or private individuals and organizations will be welcome.

Sincerely,

DON FUQUA
Chairman

DF:Fcw

PROCEEDINGS OF THE
BUILDING ENERGY RESEARCH WORKSHOP

Carmel, California
January 12-14, 1983

Sponsored by:

United States House of Representatives
Science and Technology Committee

United States Department of Energy

Electric Power Research Institute

Gas Research Institute

National Association of Home Builders
Research Foundation

American Institute of Architects

American Society of Heating, Refrigerating,
and Air Conditioning Engineers

Proceedings prepared by

Science Applications, Inc.
McLean, Virginia

May, 1983

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INTRODUCTION AND OVERVIEW

On January 12-14, 1983 a workshop was held on Building Energy Research, sponsored by the House Committee on Science and Technology, the U. S. Department of Energy, the Electric Power Research Institute, the Gas Research Institute, the National Association of Home Builders Research Foundation, the American Institute of Architects and the American Society of Heating, Refrigeration and Air Conditioning Engineers. The objective of the workshop was to formulate a national agenda for research in energy efficiency and solar energy related to buildings.

Fifty six participants, representing the building industry, its trade associations, the national laboratories, public interest groups, private sector research organizations and federal agencies, were invited by the co-sponsors to attend the workshop. They worked together in panels oriented around specific research areas, as follows:

I. Component and Subsystem Research.

Panel I.a. Materials, Storage and Envelope Subsystems.

Panel I.b. Windows, Daylighting and Passive Solar.

Panel I.c. Ventilation, Infiltration, Moisture Control and Indoor Air Quality.

II. Whole Building Performance Research.

Panel II.a. Residential and Other Small Buildings.

Panel II.b. Commercial or Large Buildings.

III. Technology Transfer and Disincentives to Energy Efficiency

A list of participants, by panel, is provided below. The workshop did not include, by design, building energy equipment or active solar energy systems.

Each panel was asked to divide its research area into topics and prepare, for each topic, a two page paper discussing the objective of the research; its importance to the goal of improving energy efficiency and

solar utilization in buildings; the urgency of addressing the activity; the stage of completion of the research; the level of effort and time required to bring it to a stage appropriate for private sector product development to begin; the results required and the most effective way to accomplish the objective. The papers, along with charts summarizing the stage of completion, urgency, level of effort required and method of accomplishing the objective are presented as the text of these proceedings. Although no two-day workshop could hope to produce an exhaustive and definitive research agenda, the co-sponsors consider the recommendations made by the panels to consititute an excellent first step.

The proceedings were typed and distributed to the workshop participants for review by Science Applications, Inc. under contract with the Electric Power Research Institute. Comments and corrections were incorporated into the text by SAI, working closely with the panel chairmen. The Workshop co-sponsors wish to thank Dr. David Ross of SAI for his excellent work in editing the proceedings and preparing the summary charts.

In addition to the detailed research recommendations prepared by the panels, the workshop produced agreement among the co-sponsors on the need to continue the very useful exchange of ideas that was begun at the meeting. The co-sponsors therefore agreed on a set of proposals, described below, for further coorperation in the building energy research area.

Overall, this was a very fruitful and productive workshop which the co-sponsors hope will lead to further cooperation between the public and private sectors in implementing a national building energy research agenda.

CO-SPONSORS' PROPOSALS FOR FURTHER COOPERATIVE EFFORTS

In order to continue the dialogue begun at this meeting the co-sponsors have agreed on a number of activities for further possible cooperative work. These activities were selected based on perception of need and likelihood of achieving significant results.

1. Building Equipment Workshop. Building equipment research was deliberately excluded from consideration at this workshop, but must clearly be covered in any comprehensive treatment of building energy research. The workshop co-sponsors agreed that it would be useful to hold one or more building energy equipment workshops to exchange information and identify possible research needs in this area.

At the workshops, building equipment manufacturers and representatives of DOE, GRI, EPRI and other national research organizations would present their research and development programs. Members of the building industry would be invited to discuss their needs in the buildings equipment area. Gaps and possible areas of overlap would be identified. Technologies covered could include active solar, conventional HVAC and control equipment, appliances, lighting systems and others. The workshops could be held in coordination with the annual national symposium on building energy equipment co-sponsored by DOE.

2. Co-sponsors' information exchange and coordination meeting. The workshop co-sponsors will meet to review their building energy research programs and identify areas of overlap, gaps and possible cooperative ventures. Presentations will be made by each co-sponsoring organization as well as major private sector research groups. The workshop co-sponsors will also begin a dialogue on their intentions to fund various aspects of the buildings energy research agenda being prepared at this workshop.

3. Further workshops on specific topics related to whole building performance and barriers. The co-sponsors agreed that small focussed workshops dedicated to specific subjects are often extremely fruitful vehicles for advancing the state of the art in a field. While many of the topics in Panels Ia, Ib and Ic are covered by regular professional or trade association conferences, or scientific meetings, the subjects contained in Panels IIa, IIb and III do not appear to have such regular meetings. Therefore, the co-sponsors have encouraged the leaders of Panels IIa, IIb and III to identify specific subjects for future workshops that could be sponsored by one or more of the co-sponsors.

4. National Buildings Research Conference. The co-sponsors have agreed to evaluate the feasibility of sponsoring a regular national buildings energy research conference to review the state of the art of the entire field at a broader level than specialists' meetings. The ACEEE Santa Cruz summer studies, or this workshop, could serve as a model for such a conference.

5. Workshops on combining energy retrofits and overall building rehabilitation programs. Some analysts contend that it makes little sense to consider energy conservation retrofits apart from overall buildings rehabilitation programs. A workshop could be held to explore ways of combining the two activities.

The co-sponsors feel strongly that implementing a number of small cooperative projects is the most effective way to continue the very fruitful dialogue and exchange begun at this workshop.

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COMPONENT AND SUBSYSTEM RESEARCH
PANEL Ia: MATERIALS, STORAGE, AND ENVELOPE SYSTEMS

Varieties of natural and manufactured materials are used in the construction of buildings. It is of the utmost importance to designers and builders to have reliable data on the properties of these materials in order to produce buildings that are energy-efficient, functional, safe and durable. Accurate data on the properties of materials are also needed for modeling the thermal performance as a substitute for broad-scale testing of building elements.

Increasing the thermal resistance of a building sometimes entails increased corollary risks in fire safety, corrosion damage, air quality, and durability. Thus, a program that seeks to develop techniques to increase the energy efficiency of buildings must also develop and apply test procedures to evaluate these risks as well as the energy-saving benefits.

The continuing efforts to utilize renewable energy sources for heating and cooling buildings as a replacement for non-renewable energy has produced new concepts in the use of materials and systems, has stimulated research on innovative materials and applications techniques that would permit more extensive use of renewable energy, and has emphasized the need to understand and evaluate the dynamic performance of buildings.

Because the building industry is large and utilizes a great variety of materials and systems having different properties, it is highly desirable to develop consensus guidelines and standards for evaluating these properties to promote fair competition in commerce, to protect the building owner, and to avoid time-consuming and costly litigation.

A two-dimensional matrix, with type of building material on one axis and materials properties on the other axis, was used by this group to identify and evaluate the areas of need for research, development, modeling

and standard test procedures for building materials. Similarly, a two-dimensional matrix, with building envelope element on one axis and performance characteristics on the other axis, was used to evaluate the present knowledge of the performance of envelope systems and to identify the important areas for new or continued research and development. In addition, several materials and storage systems that could, with the benefit of research or improved performance and application, enhance the use of solar energy and reduce the requirements for non-renewable energy, were evaluated as potential near-term energy conservation options. A list of new materials, technical data and application guidelines whose longer-term development would provide new opportunities for energy conservation was prepared. The importance of good workmanship in the assembly of materials and elements into whole buildings and in interfacing utility systems with building envelopes was described, and the need for guidelines for good workmanship was emphasized.

The seven broad topics of research and development studied by Group IA were given priority ratings by the group as follows:

Topic	Priority
Building Envelope Systems	1
Insulating and Building Materials	2
Thermal Storage Materials and Systems	3
Radiation Absorber/Emitter Materials	4
Technology for the Future	5
Desiccant Materials	6
Thermal Diodes	7

BUILDING ENVELOPE SYSTEM R&D

Objective

To develop the technical basis for designing and predicting the performance of more energy-efficient envelope components and combinations. The components are walls, floors, ceiling, ground contact elements, and combinations such as the ceiling, attic space and roof. The research and development must lead to economically viable as well as technically sound systems.

o Scope

Building envelope system research and development was partitioned into five categories:

- o walls, through which energy is transferred in the horizontal direction
- o floors/ceilings/roofs, through which energy is transferred in the vertical or near vertical direction
- o elements that are in direct contact with the earth
- o combination of the first three elements into subsystem of building envelopes
- o joints and connections.

Matrix II, attached, was used to evaluate the current state of completion of research and development and to identify the need for additional A&D on building envelope elements and systems.

The research categories considered were:

1) Laboratory measurement of steady-state thermal performance primarily using guarded and calibrated hot boxes (CHB),

2) Laboratory measurement of dynamic thermal performance. The necessary equipment consists of the calibrated hot box and specially designed equipment. An example is solar simulation

MATRIX II FOR BUILDING ENVELOPE ELEMENT R & D.

BUILDING ELEMENT	RESEARCH CATEGORIES									
	Steady State Thermal Performance	Dynamic Thermal Performance	Field-Measured Thermal Performance	Moisture Transfer, Condensation, Cavity Convection	Fire Performance	Workmanship	Modeling, Heat, Air Moisture Transfer	Innovative Concepts	Retrofit Technology
WALLS									
CEILINGS/ROOFS/FLOORS									
EARTH-CONTACT ELEMENTS									
BUILDING ENVELOPES									
JOINTS AND CONNECTIONS									

added to a CHB. Another example is a roof testing facility that can measure the thermal and mass transfer through low sloped roofs under simulated weather conditions. The latter facility is needed to resolve the problems, particularly moisture that have occurred because of the use of greater amounts of insulation in commercial and industrial buildings.

3) Field measurement of thermal performance. There are currently no fully developed techniques for in situ measurements on envelope components. Under development are a portable guarded calorimeter box by the National Research Council of Canada, an energy thermal test unit at the Lawrence Berkely Laboratory, a system of heat flow sensors, and infrared equipment. These devices should be completed and made generally available.

4) Investigation of energy transfer in closed convective spaces, air exchange, moisture transfer and utility interfaces should be investigated in conjunction with the first three items.

5) Fire performance, including test procedures and modeling.

6) The effects of workmanship on the energy performance of envelope components is of great significance. For example, it has been observed that improperly applied insulation in a ceiling can increase the heat transfer through the surface up to a factor of two, due to missing sections. It is apparent that the accepted practice of custom building residential buildings is a barrier to field achievement of the improved and innovative conservation practices and techniques that implement conservation measures. A possible change in practice would be to use factory built envelope components which are assembled in the field. The implementation of practice changes are primarily institutional barriers.

7) Modeling of energy flows, including heat, air and moisture transfers. The understanding of simultaneous, interactive transfer of heat, air and moisture is poor. Design tools are needed based on experiment and analysis.

8) Innovative systems, different from standard construction practice. Super-insulated houses, double envelope houses, and sprayed foam houses, for example, should have their performances documented as a basis for recommended practices.

9) Retrofit techniques for applications that are not now economically practical. For instance, techniquestor insulating masonry walls should be developed.

Importance to the Building Industry

The design and construction of energy-efficient structures requires validation of predicted characteristics based on reliable design tools and on experimentally validated models. It is important that the quality of workmanship and inspection be upgraded in order to asssure that energy-efficient design and construction criteria are followed and realized.

Urgency

Current design practice does not adequately deal with air leakage effects, ventilated cavities, earth contact heat transfer, thermal bridging, utility interfaces, and innovative construction practices. Empirical data are needed to improve and develop reliable models. It has been amply proved that any step forward in measurement ability has resulted in design improvements. The completion of this research and development is considered urgent.

Stage of Completion and Remaining Problems

Significant work has been completed and more is in progress on characterizing and quantifying the following properties of envelope subsystems, the level or stage of completion is as follows:

- Steady State Thermal Performance.

  Walls: Substantial progress has been made.
  Ceilings, attics and roofs: early stage of development
  Floors and earth contact sub-elements: significant progress.

- Dynamic Thermal Performance.

  All elements in early stage of development.

- Field Measurement of Thermal Performance.

  All elements are in early stage of development.

- Measurement of Moisture Transfer and Condensation (dynamic mode).

Closed convective spaces, air exchange, utility interfaces, included in 1, 2, and 3 above. All elements are in early stage of development.

- o Fire Performance.

  Test procedures are close to completion. Fire modeling is in the early stage of development.

- o Upgrading of Workmanship.

  All elements are in early stage of development.

- o Modeling Energy Flow (including moisture effects).

  Significant progress in some building elements, early stage of development on others.

- o Innovative Concepts.

  Significant progress has been made in all elements.

- o Retrofit.

  All elements are in early stage of development.

Products or Results Required

The research efforts described above should be carried out so that their results will be directly applied to:

1) Improved predictive tools for designers, builders, and product manufacturers.

2) Design specification and application guides for improved and innovative new construction and for retrofitting to correct existing problems.

3) Improved systems, manufacturing techniques, and construction and installation processes.

4) Improved or expanded data bases for modeling.

Level of Effort and Time Required

The overall level of effort is estimated to be over $10 million per year for the next 3 to 7 years. Initially, 50 percent of the resources

should be devoted to measurements (steady-state and dynamic in the laboratory and field), 20 percent to retrofit developments and the remaining 30 percent to modeling (mass and energy), innovative systems and fire performance. After an adequate experimental data base is established, the resources should be redistributed to concentrate on innovation followed by measurements and modeling of the performance of the innovative constructions developed.

Research Methodology -- Most Effective Way to Accomplish Objectives

1) Establish response characteristics of envelope systems under dynamic conditions for the purpose of developing and validating reliable modeling techniques. Such modeling can substantially reduce the need for complex, time-consuming and expensive full-scale and in-situ testing. The models must be based on a reliable data base derived from extensive laboratory and field measurements.

2) Develop simplified predictive tools and applications guides for use by designers, builders and product manufacturers.

3) Develop new and improved envelope systems, products, manufacturing techniques, and construction and installation processes based on 1) and 2) above.

4) Establish means to implement the improvements developed in 3) above.

These research and development programs should be carried out as a cooperative effort between the public and private sectors utilizing specialized laboratory facilities largely in place, and continuing to use the consensus standards organizations (ASTM, ASHRAE, ANSI) to promulgate standard test procedures and guidelines and to issued performance data for design purposes.

SUMMARY OF THE BUILDING ENERGY RESEARCH WORKSHOP

	STAGE OF COMPLETION			ANNUAL LEVEL OF EFFORT			TOTAL LEVEL OF EFFORT			TIME REQUIRED			MEANS OF ACCOMPLISHMENT			URGENCY OF ACTIVITY		
	IN EARLY STAGE OF DEVELOPMENT	SIGNIFICANT PROGRESS ALREADY MADE MUCH MORE REQUIRED	QUITE CLOSE TO COMPLETION	$1 MIL OR LESS	$5 MIL	$10 MIL OR MORE	$1 MIL OR LESS	$5 MIL	$10 MIL OR MORE	3 YEARS OR LESS	3-7 YEARS	10 YEARS OR MORE	GENERIC RESEARCH AND/OR MATERIAL SCIENCES ETC	APPLIED RESEARCH COMPONENT/PRODUCT DEVELOPMENT	FIELD TEST, VALIDATION AND DEPLOYMENT	CRITICAL	IMPORTANT	MINIMAL
BUILDING ENVELOPE SYSTEM R&D	•					•			•		•			•		•		
THERMAL STORAGE MATERIALS		•			•				•			•	•	•		•		
RADIATION ABSORBER/-EMITTER MATERIALS		•			•				•			•		•			•	
DESICCANT MATERIALS AND SYSTEMS	•				•				•		•				•		•	
THERMAL DIODES		•		•				•			•		•				•	
INSULATION AND BUILDING MATERIALS			•		•			•		•			•	•		•		
TECHNOLOGY FOR THE FUTURE		•			•				•			•	•			•		

1A COMPONENT & SUBSYSTEM RESEARCH
MATERIALS, STORAGE & ENVELOPE SUBSYSTEMS.

INSULATING AND BUILDING MATERIALS

Objective

To identify the research and development projects, test procedures and installation standards of high priority for various building materials that are required by the industry to construct energy-efficient buildings.

o Scope

The building materials that were considered in this evaluation are: insulating materials by type, wood and wood products, plastics, concrete and masonry, metals, vapor retarders, sealants, composites and laminates. In addition, the need for generic test procedures and installation standards or guidelines was determined.

The broad property categories for each material that were considered are: thermal, fire, corrosion, durability/aging, density, health effects, moisture and mechanical. The more detailed properties in each category that are of importance are listed in Table 1, attached. The panel also identified future innovative products and materials technology that are needed or that have potential for development. These are treated as a separate topic.

Importance to the Building Industry

Materials are the building blocks of building elements and whole buildings. The performance of these larger systems can not be reliably and accurately determined unless the properties of the constituent materials are known. Inadequate knowledge of materials properties can lead to an inadequate, unsafe or unhealthy building environment, inefficient energy use and, sometimes, to costly and time-consuming litigation. Good data on material properties are also needed in order to develop effective models for building performance.

Urgency

Since the application of insulation is one of the easier and more cost-effective means of reducing the energy requirements of a building, it is urgent that the test methods and market data on various insulations be relevant and accurate. Likewise, it is important that these materials not introduce health or fire risks and that they remain chemically and mechanically stable for many years. The wide range of materials used as insulation makes it especially difficult to produce test methods that are equitable and that can receive consensus support.

Accurate data on the properties of other building materials are also needed to provide an adequate technical foundation for the design and construction of energy-efficient buildings.

Stage of Completion and Products or Results Desired

Significant progress has been made on the determination of the properties of many of the currently used materials. However, there are a considerable numbers of test procedures and property determinations that are incomplete or inadequate. Some of these are not useful for dynamic analysis of heat transfer, some are not suitable for modeling techniques, some have been developed for particular classes of materials and are not generic in nature, and some are under litigation in this highly competitive market.

The status of property determinations, test procedure developments, and application guidelines for the various materials listed in Table 1 is as follows:

- Generic Test Procedures

  Thermal Properties: Significant progress has been made in steady-state technology. Dynamic measurements are in the early stage of development, and require apparatus development, analysis and standard test methods.

Smoldering Combustion: Significant progress has been made on a generic test procedure for smoldering initiation. Work is in progress on a test method for study of transition from smoldering to flaming combustion. This research should be continued.

Corrosion: Significant progress has been made on development of a generic test, which needs completion.

Durability/Aging: Continued product testing is needed.

Density: Laboratory and field tests are in progress on selected materials. A generic test needed.

Health Effects: Maximum allowable concentrations under continuous exposure should be established for selected contaminants.

Moisture: Improved measurement capability is needed under both steady-state and dynamic conditions.

Mechanical: Adequate test methods are available. Specific applications are needed.

o Inspection and Installation Standards

Limited efforts for installation standards for some types of insulation have been undertaken by ASTM. A few standards exist for inspection. Both types of standards are needed to obtain the full performance potential of materials. Acceleration of the existing processes for generating installation and inspection standards is greatly needed to realize the benefits of available information.

o Insulations by Type

1) Cellulose

Material properties are generally known. Greatest need for research exists for fire, corrosion, and field density properties. There is a modest need for research on the effect of moisture and progressive loss of needed chemicals on product properties. Efforts on steady-state thermal properties and health effects are complete. Transient thermal properties and convection effects require further study. Completion of research on smoldering combustion is especially important to this type of insulation.

2) Mineral Fiber

Most material properties have been thoroughly studied for batts and blankets. Studies on transient properties are needed for both batts and loose-fill types. The current highest priority is the quantification of field behavior of loose-fills with respect to settling and the development of representative laboratory tests. Research on the quantification of conduction, convection and radiation heat transfer in fibrous insulation is of intermediate urgency.

3) Cellular Plastics

Most properties of plastic board insulations are known. Significant problems have developed in the field application of urea formaldehyde foams (UFF) in two areas; namely, shrinkage (with corresponding loss in thermal resistance) and chemical decomposition (with attendant health effects). The use of urea formaldehyde foams in residences and schools has been banned in the U. S. The need for further research as well as the Canadian study of procedures for removing UFF insulation already installed should be assessed. Research is needed to develop an acceptable substitute for UFF because of its adaptability to the retrofit insulation market. Current studies on the radiation and gaseous diffusion properties of cellular plastics should be continued because of the possibility of attaining property improvements of up to 25 percent.

4) Reflective

Laboratory and field studies of the thermal and aging properties of reflective insulation are needed as a basis for establishing consensus standards. Such test methods do not now exist. Handbook data are needed on the thermal resistance of accordion-pleated reflective insulation products consisting of one or more layers of pleated reflective foil supported by one or more layers of heavy non-reflective paper. The effect of condensed moisture and dust on the reflective properties of this type of insulation needs further study.

5) Low-Density Concrete

The relation of density and thermal resistance of the principal types of low-density concrete has been reasonably well established. The effect of moisture content on thermal resistance under actual use conditions in roofs and walls needs further research and documentation.

6) Expanded Minerals

The properties of perlite and vermiculite are reasonably well documented and are not in urgent need of further research.

7) Innovative Insulating Materials

Research is needed to develop plastic foam insulation having the desirable field application features of urea formaldehyde foam, but without the unfavorable properties of shrinkage and health effects of that product. A high priority should be given to research on the thermal resistance and light transmission properties of microporous aerogel insulations.

o Other Building Materials

1). Wood and Wood Products

High priority should be given to research on the use of wood and wood products in solar-oriented construction, on the development of compatible fire retardants and moisture decay inhibitors for wood, on guidelines for permissible alternate wetting and drying of wood in wood envelope construction. Intermediate priority should be given to research on the thermal resistance and thermal storage of log walls by type, and the effect of jointing methods and fissures in log construction on thermal performance.

2) Plastics

The need for research is urgent on the thermal and light transmission properties and the aging properties of plastic sheets used in solar collectors. Of intermediate priority is research on the thermal, fire, mechanical and aging properties of plastic materials used as interior or exterior elements of building envelopes.

3) Concrete and Masonry

Because of the wide use of concrete and concrete and clay masonry units in providing thermal storage capacity in buildings designed to utilize renewable energy, it is important to have adequate data on the thermal response of these materials to dynamic climatic conditions, including solar exposure. There is an urgent need to evaluate the present test methods for determining thermal conductivity, specific heat and thermal diffusivity of these materials, and the influence of moisture content on

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their values. A data bank is needed on the thermal properties of concrete and masonry units covering the range of raw materials, densities, and moisture contents typically encountered in building practice. Research is also needed on the control of moisture and air leakage in concrete and masonry building elements.

4) Metals

The principal property of metals applied to buildings that needs further research is corrosion potential. Metals in contact with dissimilar metals, or with non-metallic materials including insulation (which often contains impurities) can set up galvanic action in the presence of moisture that can seriously damage metal pipes, electrical conductors, reinforcing bars, or structural members.

5) Vapor Retarders

The vapor transmission properties of most of the film materials used as vapor retarders are fairly well documented however, the corresponding data for paints and coatings is much less definitive since these materials have been principally used for other purposes in the past. It is generally recognized that the problem of continuity of vapor retarders is the principal application problem. The vapor retarder should also function as an air barrier in most building applications. There is an urgent need for research on techniques to provide continuity in vapor/air barriers involving compatibility with sealants, fastening techniques and puncture resistance to serve as a basis for concensus performance criteria. There is also a need for better documentation of the vapor transmission properties of paints and coatings.

6) Sealants

There are probably adequate test methods available for sealants. However, there is an urgent need for better handbook documentation in the retention of the elastic and adhesive properties of the different types of sealants over extended periods of time when exposed to changing temperatures and environmental effects.

7) Composites and Laminates

Insulations of various kinds are combined at the factory or in the field with wood, masonry, plastics, metals and

other substances to produce composite materials or laminated products to be used in building envelopes. Frequently, the properties of the component materials are known. However, there is an urgent need for a set of generic test procedures for evaluating composite or laminated elements when used in particular parts of a building, e.g., walls, roofs, etc.

Level of Effort and Time Required

Some parts of the materials research and development program could be carried to the point of commercial development or consensus standards in about 3 years, other parts might require 5-7 years. The level of effort required is estimated at about $3 million per year.

Methodology -- Most Effective Way to Accomplish Objectives

The development of new products such as foamed insulation, plastics, composites and laminates should be done primarily in industry product development departments or in private research laboratories under contract.

Generic test procedured, installation and inspection guidelines can be most effectively studied and developed in university or government laboratories that are disassociated from the marketing of products. Standardization should utilize the consensus process.

Data on materials properties can be developed effectively in association laboratories, but effective programs depend on the availability of staff with experience and experimental ability in the particular field of study.

Table 1. MATERIAL PROPERTIES OF INTEREST

Thermal

- Thermal Conductivity
- Thermal Resistance
- Specific heat
- Thermal Diffusivity
- Thermal Radiation Emittance
- Air Permeability
- Useful Temperature Limits
- Effects of Aging
- Internal Convection
- 3-Dimensional Properties
- Reflectivity
- Solar Heat Transmittance
- Light Transmission
- Radiation Absorptivity

Fire

- Flame Spread
- Smoldering
- Smoke Developed
- Fuel Contributed
- Rate of Burning
- Leaching of Fire Retardants
- Toxicity
- Retardation

Corrosion

- Moisture Effects
- Permanence of Inhibitors
- Trace Elements (Purity)
- Uniformity in Composition

Durability/Aging

- Dimensional Stability
- Temperature/Moisture Cycling
- Freeze/Thaw
- Weathering
- Cracking
- Dustiness
- Chemical Stability
- Emittance/Absorptivity Degradation
- Warping
- Shrinkage

Density

- Settled Density
- Variability
- Interrelationships

Health Effects

- Animal/Rodents
- Fungus/Bacteria
- Odor
- Toxicity
- Carcinogens
- Particulates/Gases
- Itching/Allergies
- Radon Gas
- Safety Factor

Moisture

- Water Vapor Permenace
- Water Absorption/Adsorption
- Capillarity
- Leaching
- Hydrolysis

Mechanical

- Compressive Strength
- Tensile Strength
- Flexure
- Shear
- Fasteners/Nailability
- Adhesives
- Open Cell/Closed Cell
- Friability
- Impact Resistance
- Surface Roughness
- Physical Integrity
- Ease of Application
- Uniformity in Composition
- Fiber Structure
- Warping and Sagging

Table 1. MATERIALS AND COMPONENTS WITH SPECIAL RESEARCH NEEDS

Insulating Materials

Cellulose

- Fire Retardants
- Fiber Structure
- Corrosion Inhibitors
- Batt Process
- Product Variability

Mineral Fiber

- Settled Density
- Thermal Resistance vs Thickness
- Slag Content
- Uniformity in Composition

Reflective Insulation

- Thermal Resistance
- Corrosion
- Change in Reflectivity
- Uniformity of Air Spaces
- Emissivity

Cellular Plastics

- Shrinkage
- Odor
- Cellular Structure
- Fire Retardants
- Application Gun

Low-Density Concretes

- Thermal Properties
- Corrosion
- Durability
- Mechanical Properties
- Moisture Content

Expanded Minerals

- Thermal Resistance
- Settled Density
- Corrosion
- Uniformity in Composition

Other Materials

Wood and Wood Products

- Moisten Absorption
- Dimensional Stability
- Fungus/Dry Rot
- Thermal Resistance
- Toxic Emissions
- Uniformity in Composition

Sealants

- Elasticity
- Adhesion
- Aging
- Corrosion
- Permeability
- Temperature Effects

Vapor Retarders

- Permeability
- Fire Properties
- Durability
- Tear Strength
- Puncture Resistance
- Perforations

Plastics

- Aging
- Shrinkage
- Odors
- Fire Properties
- Mechanical Properties
- Uniformity in Composition

Table 1. MATERIALS AND COMPONENTS WITH SPECIAL RESEARCH NEEDS
(Continued)

Other Materials (continued)

Metals

- Thermal Resistance
- Corrosion
- Reflectivity
- Compatibility Between Materials

Concrete and Masonry

- Thermal Properties
- Moisture Content
- Fire Properties
- Mass Effects

Components

Windows, Skylights, Glass Doors

- Solar heat Transmission
- Thermal Energy Transmission
- Light Transmission
- Air Leakage
- Warping
- Corrosion
- Condensation

Opaque Doors

- Thermal Resistance
- Air Leakage
- Warping and Sagging
- Moisture Effects
- Fire Properties

Service Systems

Service System Interfaces

- Air and Moisture Leakage
- Insulation Displacement
- Fire Properties
- Expansion and Contraction

Space Heating and Cooling Systems

- Thermal Resistance
- Thermal Bridges
- Air Leakage
- Moisture Transfer
- Reflectivity

THERMAL STORAGE MATERIALS AND SYSTEMS

Objective

To establish the properties and effectiveness of thermal storage materials and systems in utilizing renewable or waste energy and in reducing the peak demands and costs of non-renewable energy.

Importance to the Building Industry

The development of cost-effective thermal energy storage materials will reduce the energy costs for buildings and the demand for the energy supplied by non-renewable sources. Thermal storage will increase the energy efficiency of solar energy and heat pump systems and other plant systems in building. It will also reduce the peak energy demands on utility systems.

Urgency

Passive heating systems are benefitted by the cost-effective storage of energy during the day to be available during the night and other peak demand periods. The characterization of the thermal storage properties of masonry and concrete materials can significantly influence the design of concrete, brick and masonry buildings and enhance their energy efficiency in many climatic areas. The wide usage of thermal storage materials in connection with passive solar and heat pump systems could postpone or avoid the need for constructing new electrical generating capacity.

Stage of Completion and Remaining Problems

The two types of thermal storage include sensible heat storage and latent heat storage. Sensible heat storage may be further classified as: a) remote water storage, b) water walls, c) remote rock or gravel storage, and d) building element mass, e.g., concrete, masonry. Latent heat systems may be classified as: a) solid/solid phase change materials, b) solid/liquid phase change materials, and c) liquid/gas phase change systems.

Remote thermal storage systems using water, rocks, gravel and phase change salts and salt mixtures were extensively researched as much as two decades ago. A number of experimental houses were built to demonstrate the benefits of energy storage. Some of the problems that developed in the phase change systems were the hysteresis in the phase change from liquid to solid, the need for nucleation to initiate solids formation, the design of storage systems for effective absorption and release of energy and the corrosion of containers. There is ongoing work on phase change materials in both the public and private sectors. Most of this research addresses the phase change materials themselves with some research on containment. This research is still in the developmental stage.

Products or Results Required

Development of new phase change materials or modifications of the heat transfer process for previously used materials to reduce or eliminate hysteresis, subcooling, need for nucleation and corrosive effects, should be undertaken.

Improvement or optimization is needed for the size, shape and surface characteristics of the material or the containers for phase change materials to enhance the heat transfer to and from the material and to make all the phase change material available for heat absorption or release.

Significant progress can be made with the conventional materials considered here as sensible heat thermal storage materials. For example, magnicite is added to brick for coloration, but it has an enormous effect on thermal storage. It is a costly additive. Work should be supported to investigate the firing process and to develop low cost additives that would serve multiple purposes. A further example would be the development of an additive to gypsum that could be used in wall board to enhance its thermal mass properties.

Completion of the research regarding the properties, applications and performance of sensible heat thermal storage materials is important so that

appropriately designed and selected thermal storage components may be incorporated into building designs in the near future to help reduce the energy consumption resulting from the use of buildings. This research may also lead to the development of new applications of existing materials for thermal storage.

Liquid sensible heat thermal storage materials research should be directed toward the development of adequate containment methods.

Thermal storage containment should also be considered as a daylighting element in addition to thermal storage through the use of translucent materials and/or containers. Solid/solid materials should also be considered as daylighting elements.

Development and verification of analytical models for evaluating the performance of heat storage systems in relation to climatic factors and building loads is needed.

Construction, operation and measurement of the performance of demonstration buildings should be programmed to verify the analytical models and to provide data for design guidelines for heat storage systems.

Level of Effort and Time Required

The estimated level of effort and time required to complete the research and development program described below are $2 million per year and 8 years, respectively.

Methodology -- Most Effective Way to Accomplish Objectives

Most materials currently in use for thermal storage are non-proprietary so the private sector would have little incentive to support research and development programs on such materials. However, innovative materials and systems are possible and some manufacturers with appropriate technical

staff would undertake the development of new storage systems such as the dual use of thermal storage elements as daylighting apertures, or combined thermal storage and heat pump systems.

The following types of research programs should be carried out cooperatively by public, private and university research organizations to produce the needed products and technical information on thermal storage systems.

1) Improved techniques for modeling, measuring, analyzing and testing thermal storage characteristics of storage materials. To include dynamic cycling and application-specific performance, i.e., direct gain, thermal storage wall systems, etc.

2) Characterization of thermal energy storage materials properties (particularly specific heat, thermal conductivity, thermal diffusivity, density, absorptivity and emmisivity) and their effectiveness in buildings.

3) Analytical studies on latent heat storage materials to increase understanding of supercooling, nucleation, phase migration and hysteresis in solid state phase change materials.

4) Studies of solar effects on building components of large mass.

5) Systems analysis to determine how the thermal properties of storage materials can be optimized for remote storage in exterior or interior building elements.

6) Study of the use of thermal storage materials of either the sensible or latent heat types in cooling applications either as passive elements or in combination with heat pumps or mechanical cooling systems to improve their efficiency.

7) Development of standard test procedures to evaluate the performance of thermal storage materials and systems under simulated use conditions.

8) Study of the effects of thermal coupling and thermal bridges between the thermal storage elements and other building components and thhe environment.

9) Development of innovative thermal storage systems with translucent containers for dual use as daylighting apertures.

10) Development of performance criteria for the containers for thermal storage materials including corrosion, leakage, fire and health properties, thermal stratification, and heat exchange efficiency.

11) Development of design guidelines and siting methods for thermal storage materials integrated into buildings.

RADIATION ABSORBER/EMITTER MATERIALS

Objective

To develop new or improved absorption-transmission-emission materials that can alternatively absorb or reject solar energy to facilitate control of the thermal transmission of building elements.

Importance to Building Research

The success of this research would have a significant impact on building heat loss. For example, control of the external surface temperature of a building could significantly reduce the temperature difference across a wall and reduce the accompanying flow of heat.

Urgency

Demonstration is needed that a surface material with properties that can alternately absorb or emit energy will significantly reduce heat flow.

Stage of Completion and Remaining Problems

Some research has been done on materials with selective absorption and radiation characteristics in certain wave-length bands. Materials with spectral properties that are modified by sunlight have been used in other fields, but have not been applied to building materials. Research on building materials with selective or adjustable spectral properties is in an early stage of development.

Products or Results Required

The products of this research will be development of new or improved selective coatings that could be utilized by the building industry. These

coatings would have switchable or tailored spectral properties. Also, the spectral properties of presently used building materials would be made available.

Level of Effort and Time Required

The estimated level of effort and time required for the research and development program outlined below to produce prototype materials ready for commercialization are $1.5 million per year and 8 years respectively.

Research Methodology -- Most Effective Way to Accomplish Objectives

Research would be carried out in three phases: 1) proof of concept 2) development of prototypes and 3) commercialization.

The desired absorption-transmission-emission requirements will be defined and candidate materials evaluated. New materials will be developed and existing materials will be improved and tested for thermal performance and durability. In some instances, new test methods will be developed. Research will focus upon improving thermal performance and spectral radiation properties, bonding of materials to substrate, thickness insensitive coatings, inexpensive fabrication techniques, and inexpensive application techniques.

The following research agenda is recommended:

1) Characterization of coating spectral properties, durability, and sensitivity to process parameter changes of selective absorber types, including cermet, semiconductor/metal absorbers, candidate coatings and current building materials.

2) Investigation of selective emitters to enhance heat rejection of building envelope for radiative cooling.

3) Development of materials and products for use by designers and builders, with reliable application and performance information.

4) Search for coatings which may be electrically, thermally, or otherwise switched from absorbing to reflecting in order to moderate building surface temperature.

TECHNOLOGY FOR THE FUTURE

Objective

To identify materials, products and procedures that could be developed in the next decade which would fill recognized technology gaps, provide more effective use of renewable energy, promote new construction techniques, and improve the application of energy conservation technology.

Importance to the Building Industry

Breakthroughs in insulating materials with higher thermal resistance, a transparent insulation for use in fenestration and as exterior covering for masonry walls, better foamed polymers for the retrofit of buildings, the ability to adjust the thermal resistance of insulation, practical application of movable insulation, coatings for exterior walls with switchable radiation properties, and a broadened data base of materials properties would provide new stimulus in building design and produce important new options for energy conservation in new and existing buildings.

Urgency

New materials with promise for significantly improved properties for energy conservation are being studied in various industry and public sector laboratories. It is urgent that these promising developments be supported for the next 5 to 10 years to determine whether or not they can provide new energy conservation technology that is cost effective.

Products or Results Required

The following materials, products and procedures would significantly decrease the non-renewable energy requirements of buildings and provide the basis for more energy-efficient designs:

1) A spectrally transparent insulation for masonry walls

2) Insulation with significantly higher thermal resistivity for building envelopes

3) Improved foamable polymers for the retrofit of buildings

4) Insulation materials and systems with adjustable thermal resistance

5) Composite insulated wall systems having structural properties for modular or rigidized construction

6) Performance criteria and test procedures for movable insulation

7) Broadened data base on materials properties for both static and dynamic design and for modeling

8) Consensus application and inspection guidelines or standards for materials installation.

Stage of Completion and Remaining Problems

Prototype samplers of a microporous silica gel insulation board have been produced that promise to have a thermal resistance greater than 10 per inch. This material is being studied in various laboratories to determine its thermal properties and explore its other properties.

Various types of insulated wall sections, prefabricated as composites or laminates have been used in warehouses and prefabricated buildings over the last two decades, and insulated masonry composites are being explored. These subsystems require further development to be used in the competitive building market.

New materials that have heat and light transmitting or absorbing properties suited to passive solar construction are being studied in various laboratories. Building elements that facilitate heat gain of a building during certain climatic conditions and that can be modified or adjusted to facilitate heat loss under other conditions are in an experimental stage.

A beginning has been made by ASTM in the development and promulgation of consensus guidelines for the application of a few types of insulation. This process needs to be continued and broadened to document good construction and inspection practices for energy efficent buildings.

Level of Effort and Time Required

It is estimated that $1.5 to $2 million per year for 5 to 10 years would be required to explore and field test prototypes of the materials described in the first five items above. The procedures described in the last three items could be accomplished in 5 years at an estimated cost of $1.5 million per year.

Methodology -- Most Effective Way to Accomplish Objectives

The development of new materials based on advanced physics concepts should be done in university, industry or government laboratories having staff with a good background in experimental physics. These laboratories could carry a new concept to the prototype stage for field testing. Commercialization of such materials and products should be left to industry.

Generic test procedures for a class of materials can often be developed best by university or government laboratories where the influence of the marketplace is least likely to have an impact.

The promulgation of consensus application and inspection guidelines and standards should be carried out by national consensus standards organizations. Initial drafts of such documents can be prepared by any public or private sector group with the necessary technical background and staff.

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DESICCANT MATERIALS AND SYSTEMS

Objectives

Development of direct-control desiccant systems to absorb moisture load within the building environment using low-grade or renewable energy (solar or other) for regeneration, thus reducing other building energy demand. The cooling load on an air conditioner can be reduced by direct removal of moisture using a desiccant and a solar energy regeneration process. This reduces non-renewable energy consumption for the air conditioning.

Importance to the Building Industry

The design and operation of solid desiccant cooling systems based on desiccant dehumidification/rehumidification concepts are relatively simple (hence reliable), can operate with low-grade heat sources, such as solar, for regeneration (60 to 185°F). Dehumidification systems may be economically viable in concert with vapor compression cooling systems. These techniques restructure air conditioning functions, incorporating discount dehumidification in such a way that (a) inexpensive flat plate solar collectors can provide the required heat; (b) the COP (coefficient of performance) of the discount dehumidification subsystem is significantly increased; and consequently (d) purchased energy is reduced sufficiently to make over solar desiccant cooling both practical and cost-effective. Some estimates are that desiccant cooling techniques can displace 30 percent of the total energy requirements for cooling in buildings.

Stage of Completion and Remaining Problems

The basic problem is the energy required for regeneration of the desiccant in driving off absorbed moisture. The principal obstacle to the application of cost-effective direct-contact desiccant dehumidification and

cooling has been the performance of the available desiccants. More specifically, in solid desiccant systems, the problem areas are: the cost, performance and degradation of silica gel (the most commonly used solid desiccant) and improvement of the absorption/ desorption properties of zeolites and molecular sieves. For cooling systems using liquid desiccants (calcium and lithium chloride, lithium bromide, triethylene glycol), the basic problem has been the determination of optimum absorption properties of binary and tertiary liquid desiccant mixtures. Advanced systems to use desiccant materials must be developed.

Products or Results Required

1) Development of new desiccant mixtures having improved absorptive properties.

2) Extension of the number of useful absorption/desorption cycles in silica gel.

3) Latent heat load reduction to be used in concert with conventional cooling.

4) Solid desiccant dehumidification cooling systems in the 3-ton range with system COP's in the 1.2 to 1.5 range.

5) Prototype liquid desiccant systems and hybrid desiccant vapor compressor chillers in the 10 to 25 ton range.

The result of this materials research program would be the development of desiccant dehumidifier systems having significantly improved performance and lower cost characteristics.

Level of Effort and Time Required

The estimated level of effort and time required to bring new or improved desiccant systems using solar regeneration to a position ready for commercial production is $2 million per year for 5 years.

Research Methodology -- Most Effective Way to Accomplish Objectives

Research should be directed to development of building cooling systems which have the following characteristics:

(1) The dehumidification task (latent cooling) is separated from the temperature control task (sensible cooling) and accomplished with a moisture-absorbing liquid desiccant.

(2) Subsequent sensible cooling, relieved of the need to chill to the dew point to condense out moisture, can be at a more efficient higher temperature level, thus increasing chiller efficiency.

(3) The dehumidification subsystem is configured so that the moisture-laden desiccant can be dried with 130-140°F solar energy, which is available via flat plate collectors during a high percentage of the cooling season (for example, about 80% of the time in Washington D.C.).

(4) The efficiency of the desiccant regeneration (drying) process is further increased - and solar collector area reduced - by a heat recovery technique.

Thus cost and energy savings are at two levels: the subsystem level and, with efficient organization and integration of subsystems. the overall system level as well.

The research is to be phased as follows:

1) Establish system and materials criteria.

2) Screen materials and select candidate materials.

3) Test and evaluate materials in prototype test facility.

4) Test final system in engineering field test.

THERMAL DIODES

Objective

To utilize anisotropic (one way) thermal transport mechanisms to provide heat flows that reduce the building nonrenewable energy consumption.

Importance to Building Industry

The objectives of the search for anisotropic thermal transport mechanisms, such as thermal diodes or other means for allowing heat to flow predominantly in one direction, are to save energy and reduce heat loss by:

1) Improving energy distribution in buildings

2) Permitting the use of more exposed building surfaces for energy collection

3) Providing efficient non-mechanical heat transport over longer distances so as to bring heating or cooling to the interior zones of buildings

4) Permitting simple control of excessive heating or cooling.

5) Transferring significant amounts of thermal energy with a small temperature difference.

Urgency

The selective movement of heat using thermal pumping is important in the application of passive heating and cooling to buildings.

Stage of Completion Remaining Problems

The basic concepts of anisotropic thermal transport are known. The application to building technology will require innovative systems and materials combinations to be effective with small temperature differences.

Devices, such as heat pipes, that transfer heat efficiently in one direction are now used in advanced-technology plants and in some heat exchangers, but have not been used as integral parts of building structures. Present solar heating systems often operate near 20 percent efficiency because of poor heat transfer to the building interior and because the system itself loses collected energy to the ambient air. Some calculations indicate that the use of diodes could double the efficiency of passive collection while transporting energy to and from the interior of the building. Among the many forms of such non-mechanical systems, heat pipes could couple an energy source, such as a solar-heated exterior wall with an energy sink, or storage system, and could be controlled by a simple valve.

Products or Results Required

- Investigations in the field of anisotropic thermal transport mechanisms should lead to the incorporation of cost-effective non-mechanical systems in buildings.
- Heat pipe technologies, vapor refluxing loops coupling exterior building elements to interior thermal storage components.
- Convective liquid columns coupling building interiors to evaporatively cooled roofs.

Level of Effort and Time Required

The level of effort and time required is estimated to be $3 millio and 5 years.

Research Methodology -- Most Effective Way to Accomplish Objectives

Research in this area would be conducted as follows:

1) Analytic studies, including computer simulations, to correlate transfer rates, temperature differences, and other engineering parameters required to evaluate transport mechanisms

2) Experimental and theoretical investigations to determine feasibility of candidate systems

3) Seasonal tests under actual building conditions

4) Quantified performance guidelines to be provided for designers.

Within the above suggested research agenda, the following topics should be investigated:

1) Unidirectional and enhanced transfer between collection and storage

2) Transport between thermal storage at moderate temperatures and building spaces

3) Vapor-phase thermal transport system concepts for one-way reversible movement

4) Corrosion and containerization of liquid systems

5) Fire damping in air systems.

WORKSHOP IB COMPONENT AND SUBSYSTEM RESEARCH
WINDOWS, DAYLIGHTING, AND PASSIVE SOLAR

Introduction

This group reviewed the thermal, lighting and visual functions of apertures, and considered their integration and performance at the perimeter zones of buildings. The energy implications of these building elements are significant, because apertures account for more than 20 percent of the energy cost in typical buildings. The aggregate impact attributable to apertures is about 5 percent of total national energy consumption.

Research is required in two major complementary areas. First, current application of existing fenestration materials and systems has resulted in designs that fall far short of potential energy savings because our existing base of knowledge on the technical performance of fenestration systems is incomplete and frequently incorrect. Improved design guidelines and performance specifications for architects and engineers must be based on a more complete understanding of the multiple energy-related functions of windows and skylights in buildings. Effective research into new glazing materials also requires a comprehensive understanding of all fenestration performance characteristics. Development of the technical data base on fenestration performance to support the objectives described above will require refinement, development and validation of improved predictive models of fenestration performance.

Second, where proper utilization of existing materials and systems still falls short of achieving potential savings, breakthroughs in new fenestration technologies will be required. These may result in more cost-effective savings than are currently achievable and will also result in substantial additional savings that may not be achievable with existing technology at any reasonable cost.

Current fenestration assemblies do not respond adequately to changing environmental conditions and internal requirements. The beneficial contributions of solar heat gained during a winter day can be lost at night through the same aperture. In other seasons, that solar heat gain can cause discomfort and impose an additional load on building cooling systems. Electrical lighting loads that account for significant usage levels in commercial buildings could be greatly reduced by daylighting, but transmission at visual frequencies and visual comfort are not reduced by reflective glazings employed to reduce cooling loads.

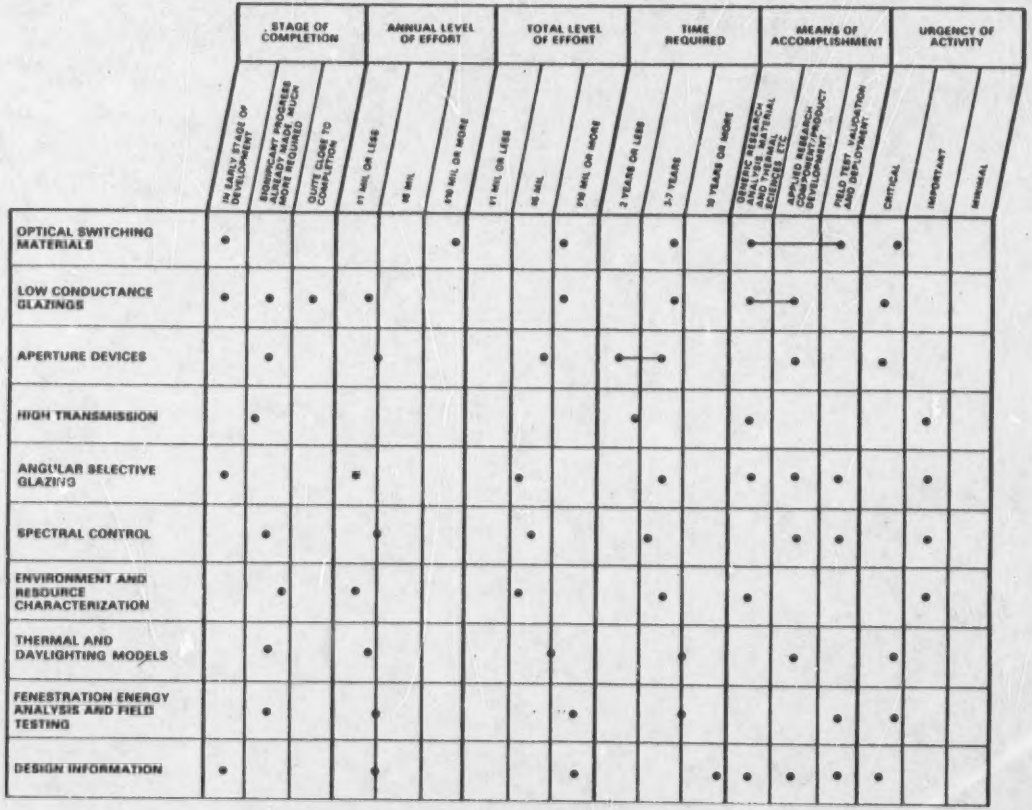
Recent major advances in materials and technologies in other fields have provided opportunities to overcome these difficulties and could improve greatly the energy and lighting performance of apertures. The transfer of such developments to buildings would make it possible both to control thermal radiation flow and to enhance visible transmission. Moreover, it is feasible to respond to dynamic conditions by introducing controllable materials in aperture coatings and glazings which could provide positive controls directed by building occupants or responsive automatically to resource availability.

Research and development activities are required to facilitate the introduction of these innovations in buildings. Such work would include the development of aperture devices, glazings with switchable, low conductance and high transmission characteristics, and controls with angular and spectral properties which would effect the reduction of energy demands for heating and cooling and electrical demands for lighting. To obtain the needed materials and components, research would include identification of candidate materials, the performance of exploratory research in laboratories and test cells, and the identification of the most promising materials and concepts to optimize cost and performance capabilities.

Development of advanced aperture materials and technology must be accompanied by a substantial improvement in our ability to predict fenestration performance in buildings. To take a major new fenestration material from the concept state to the point where it will have a major impact

on energy utilization will take five to fifteen years and in that time frame energy valued at hundreds of billions of dollars will have been lost due to inefficient design and utilization of fenestration in new and existing buildings. Windows and skylights are particularly complex elements in the energy performance of buildings because of the multiple and often contradictory roles that play. The design and construction community (as well as the fenestration industry) needs a sound technical data base on fenestration performance that will assist in all levels of decision making. This data base must be based upon an extensive program of data collection and field monitoring of instrumented buildings and test cells as well as systematic studies of fenestration performance using validated energy analysis models. Analysis models must be expanded or developed where appropriate to account for all significant energy and load inputs, including both thermal effects and daylighting. These state-of-the-art models will also provide the basis for simplified calculation techniques, estimating procedures and design guidelines required by the design community.

SUMMARY OF THE BUILDING ENERGY RESEARCH WORKSHOP



1B COMPONENT & SUBSYSTEM RESEARCH
WINDOWS, DAYLIGHTING & PASSIVE SOLAR.

OPTICAL SWITCHING MATERIALS

Objectives

Identify and develop a series of optical switching materials that dynamically control the intensity of solar radiation transmitted through an aperture from 95 percent to 5 percent so as to minimize energy use and peak electrical demand. One class of devices would switch automatically in response to environmental conditions (e.g., temperature, solar intensity), while another could be switched at will electrically in response to occupant needs (e.g., glare control, privacy) or building energy management functions. Candidate materials should be stable, durable, homogenous and non-toxic.

Importance to Building Industry

Control of solar heat gain and light admittance through an aperture is essential to minimize building energy consumption. Buildings operate in a dynamic solar and temperature environment. Using existing glazing materials, the aperture which admits solar heating energy during the heating season also admits solar energy during the cooling season. Similarly, glazing which admits light for visual contact with the environment or for reducing illumination requirements also increases cooling loads for substantial fractions of the year for many building types in many climates. In order to substantially improve the annual total energy balance of the aperture, these dynamic solar effects must be modulated. Control of light and solar gain through fenestration has traditionally been an improtant part of building design. The fixed devices normally utilized (e.g., fins, overhangs) always represent a poor compromise between conflicting performance requirements. Operable devices such as drapes or venetian blinds are the logical response to provide some dynamic management capabilities. However, operable mechanical devices often have durability problems and high maintenance costs. An ideal solution would be to reduce the control function to occur at a microscopic level within the glazing material itself.

Urgency

Very substantial energy savings and peak load reductions can be obtained through the use of optical switching materials. The primary energy function is reduction of cooling loads while providing for daylight admittance, both of which serve to reduce electrical energy use and peak electrical demand. The favorable impact of switchable glazings on utility peak loads should be very large since the glazings would reduce cooling loads and lighting loads, the primary contributors to building electrical peaks. Reliable switching materials would also allow reduction in HVAC system in size and cost since the aperture could respond dynamically to changing environmental conditions. One square foot of unprotected glazing can impose a cooling load on the building which requires an incremental investment of as much as $\$50/ft^2$ of glass. At the other extreme, highly reflective glass eliminates daylighting opportunities. Switchable glazings would allow the aperture properties to be dynamically tuned to maximize the energy, confort and productivity benefits.

Stage of Completion and Remaining Problems

Limited overview studies have been completed for several optical switching materials. Basic candidate materials systems include:

1) Photochromic
2) Electrochromic
3) Thermochromic
4) Liquid crystal
5) Electrodeposition

Photochromic systems have had the greatest development effort as an outgrowth of sunglass applications. However, currently available materials respond passively to radiation intensity and are absorptive so they do not meet all functional criteria. The possibility of developing reflective

photochromic systems should be explored. Electrochromics have been studied as display devices, and potential materials systems that would be useful for window applications were reviewed in 1979. New studies were initiated with DOE support in FY 1982 on three promising electrochromic systems. These are all in the early stages of defining and characterizing materials performance. A review of thermochromic, liquid crystal and electrodeposition systems suggest that combined photo/thermochromic systems, reflective reversible electrodeposition systems and some classes of liquid crystal may be promising for aperture applications. All are in early stages of research.

Products or Results Required

- Basic materials research (theoretical and experimental investigations) to determine the feasibility of candidate systems
- Characterization of properties of candidate materials
- Proof of concept or prototype development
- Definition of specific functional requirements and detailed cost objectives
- Laboratory and field test programs.

No single switching materials is likely to emerg as the ideal candidate for all of the diverse building applications for which materials would be useful. This parallel development of multiple options through at least the early materials research states is required.

Level of Effort and Time Required

To move from concept to commercially available products will take 5 to 10 years and in excess of $10 million. The level of effort would be dependent upon the number of different materials systems studied in parallel.

Methodology -- Most Effective Way to Accomplish Objective

An initial 3- to 5-year program emphasizing basic materials research studies would be required to explore and characterize alternative systems and narrow the field to the solutions that appear to be most promising. These systems would then move to the prototype testing phases prior to transfer to the private sector and development of a commercial production capability. In a parallel effort, complete test data on materials and device performance would be collected.

LOW CONDUCTANCE GLAZINGS

Objective

Increase resistance to heat flow through glazing systems from present levels (R-0.9 per glazing layer) by a major factor, at least to R-5 and perhaps to R-15, while maintaining acceptable levels of optical energy transmittance (for daylighting applications), with acceptable visual clarity (at least for view window applications).

Importance to Building Industry

Heat loss through glazing accounts for about 20 percent of the heat loss from a typical building or about 4 percent of the nation's energy use. Improved R-values would reduce these losses proportionately. Passive heating applications would become even more effective if such a development were to be successful. Costly and awkward movable insulation strategies would no longer be necessary in cold climates. Building facades other than south facing could be used for beneficial net winter solar gain. Thus, building siting and orientation would become less constraining than in present passive solar applications. Also, direct-gain passive solar heating would imply much reduced levels of interior sunlight. Such high levels, at present, often lead either to large temperature swings or to uneconomic demands for large interior mass. These high light levels may also cause ultraviolet degradation of fabrics and other building contents. These problems would be reduced by low conductance glazings. The glass industry could offer a more viable product at a time when the tendency is to use less glass in buildings.

Urgency

Because of a high probability of success and a very large payoff in energy savings, the urgency of this task is very great.

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Stage of Completion and Remaining Problems

Certain technologies required, such as low emittance coatings to reduce thermal radiation flow through the glazing system, are well advanced and can almost be considered state of the art, although improvements in optical properties and durability would certainly be beneficial. To achieve the objectives, however, requires also reducing conduction and convection losses by a major factor and this is at an early state of development.

Product or Results Required

Different requirements exist, depending on the specific applications.

- o The least stringent is overhead daylighting. Here, high transmittance is not required and visual distortion is not a problem.
- o The opposite extreme is a view window used for passive solar heating. Here, solar transmittance should be at least 60 percent (winter seasonal average) and visual distortion is unacceptable.

It is likely that the former can be achieved, but the latter presents much more formidable challenges.

In most cases, the product would be likely to use low emittance coatings (also see spectral control task) to retard thermal radiation flow through the glazing. In most instances this coating will be in a protected environment and thus state-of-the-art methods can be employed.

Advancements in low emittance coatings would enhance the performance of low conductance glazing systems. There are two categories that should be distinguished as follows:

1) For use on the south facade of buildings with net winter heating requirements.

Any reduction in solar transmittance results in a serious performance degradation. The goal should be to develop coatings with an emittance less than 0.1 which decrease the transmittance by not more than 5 percent.

2) For use on other building facades.

Very low emittance values are needed and moderate reductions in transmittance are tolerable. The goal should be to achieve emittance values less than 0.05 which decrease the transmittance by not more than 25 percent.

For the reduction of heat flow by conduction and convection, there are several options, as follows:

1) Evacuation of the space between the glazings. This is probably only practical in glass-sealed glass systems and will require structural support between the glazings. This can be done on a coarse grid (2 cm or more) or on a very fine grid (fractions of a mm). This may lead to some visual distortion. This approach has the greatest potential for very high R glazings.

2) Low density transparent aerogels sandwiched between glass outer layers. If this system is evacuated, then it can be thin. If not evacuated, then a thick layer would be required (2 cm or more).

3) Convection suppression using vertical or honeycomb structures.

4) Low conductance gases.

5) Combinations of 2, 3 or 4.

Cases 1, 3 and 4 require the use of a low emittance coating to sypress radiative transfer if low conductance levels are to be aqhieved. In all cases, it would only be consistent to mount such an advanced glazing system in frames with low thermal loss characteristics. Some parallel development here would be appropriate.

An important product is information. For each system developed, both technical and design information should be provided which adequately characterizes its properties.

Level of Effort and Time Required

The research effort itself will require moderate funding of $5 to $10 million (total) over a period of 3 to 10 years. Since implementation by the glazing industry involves major changes in large-capital facilities, it will occur slowly and be very expensive for that industry. However, since this will be amortized over a large production level, the incremental cost to the consumer should not exceed the acceptable market tolerance level of about $5 per ft^2.

Methodology -- Most Effective Way to Accomplish Objective

The various approaches identified above would be carried along in parallel until one or more emerge as the leading contender(s). It is possible that more than one product will be identified, each suitable for different applications. Properties of candidate materials and systems will be characterized and cost/performance objectives established. Then experimental and theoretical investigations will determine feasibility of candidate systems. Those identified will undergo seasonal tests in test cells, in actual buildings, and accelerated tests. Properties of successful systems will be thoroughly documented.

APERTURE DEVICES

Objectives

- To improve the dynamic response capability of building apertures to climate assets and liabilities by using apertures devised to optimize:
  - Collection of useful solar heating
  - Shading to reduce heat gain
  - Visible transmission and distribution
  - Reduction of heat loss.
- To provide more complete technical information on the performance of generic devices in all of these technical characteristics. It must be emphasized that there are a large number of devices and, therefore, the emphasis must be on generic systems. Even with this emphasis, the research will have to contend with a large number of systems.
- To make significant breakthroughs in more cost-effective devices or combinations which respond to one or more of these requirements.

Importance to Building Industry

Aperture devices are physical elements which modify the thermal and visual performance of a single-glazed window. Examples are:

- Shading Devices -- exterior, fixed horizontal and vertical, movable awnings, louvers, etc.; interior, venetian blinds
- Daylighting Enhancers -- fixed light shelves, reflective movable louvers
- Movable insulation

In general, the purpose of these devices is to act as a more effective environmental f..lter between climate resources of solar energy, tempera-

ture, and wind and specific comfort or environmental requirements on the inside perimeter of buildings, with the purpose of effectively reducing the cost of energy consumption.

Urgency

Although a large body of research exists on many devices, there are serious (critical) gaps in information on almost all of these mechanisms. For example, although the thermal performance of a device may be well understood, its shading properties (shading coefficient) may not be known and its impact on the quantity and quality of daylighting under different conditions may not be known. Complete information is necessary for designers to make meaningful evaluations.

This topic should have one of the highest priorities because aperture devices have the ability to make a significant impact on all three major energy end users in buildings -- heating, cooling and lighting.

Stage of Completion and Remaining Problems

Significant work has been accomplished, especially in thermal characteristics of heat loss and heat gain reduction; however, visual characteristics of daylighting, both quantity and quality, have to be tested and measured and added to thermal characterristics, i.e., important gaps need to be filled in order for complete design and evaluation to take place.

Given increased knowledge of the thermal and visual requirements, new devices and combinations seem to be possible. These components need to be developed and tested. Particular attention should be focused on those components and devices that serve multiple functions.

Product or Results Required

- o Catalogue of generic systems and their technical performance characteristics -- both thermal and visual
- o Classification of potential new systems
- o Development of new devices

Level of Effort and Time Required

These efforts are estimated to require from 1 to 5 years, and from $6 to $7 million.

Methodology -- Most Effective Way to Accomplish Objective(s)

1) Classify and characterize existing devices

2) Identify gaps and potential new devices

3) Determine performance of existing devices using complete model studies and tests in physical models, test cells, and existing buildings

4) Develop new devices or combinations (in parallel), test devices in physical models and test cells, select most promising devices for optimization and testing in existing buildings.

HIGH TRANSMISSION

Objective

The objective is to reduce electric lighting and heating requirements in buildings through advanced optical surface treatments and modified substrate compositions to achieve up to 98 percent transmission of solar radiation through apertures.

Importance to Building Industry

Heating load is the primary energy cost for residential windows in most parts of the U. S. and represents a substantial cost even in many non-residential buildings. On the other hand, lighting represents the largest percentage of energy consumed in typical commercial buildings. Solutions which maximize solar radiation transmission can alter the role of the envelope from a net loss to a net gain. Daylighting strategies that displace electric lighting may also assist in load management and reduce peak electrical demand. High transmission glazings, in concert with other treatments such as low conductive glazings would allow east, west and even north orientations to provide net energy benefits, thus greatly expanding the potential savings and reducing siting and orientation problems associated with prior emphasis on south glazings and lower transmittance type products.

Urgency

The urgency to address this activity can best be described by its immediate overall contribution to maximizing substrate solar energy transmittance and the importance of the interdependency to the other proposed product developments, such as low conductive coatings. The required research, although relatively non-complex, has not been fully investigated and yet provides us with a unique opportunity to achieve substantial energy savings.

Stage of Completion and Remaining Problems

Limited commercialization of products which offer some improvement in overall solar radiation transmittance are in place. Conversely, more efficient theoretical approaches and laboratory proved technologies are known and should be fully investigated to maximize the potential and to determine their commercial viability. Studies should be made to quantify and qualify the numerous new approaches and to determine how best to use or incorporate them in various types of apertures.

Product or Results Required

Glazing materials which exhibit, when compared to standard substrates, substantially reduced absorption properties and anti-reflective surfaces in order to achieve maximum solar radiation transmission properties.

Level of Effort and Time Required

Research in this area should be kept independent, but should be conducted concurrently with related low conductive coatings and other daylight development efforts. The required development is not an either/or situation, but rather a complementary element, essential to overall aperture efficiency.

Methodology -- Most Effective Way to Accomplish Objective

1) Identify existing anti-reflective surface treatments and substrate compositions which offer increased solar radiation transmission.

2) Identify the most promising new approaches for anti-reflective treatments and substrate compositions.

3) Characterization of candidate compositions and surface treatments.

4) Optimize performance and cost effectiveness of anti-reflecting surface treatments and substrate compositions utilizing chemical etching, physical and chemical vapor depositions and chemical composition methods. Experimental research, test cell and field testing will be required.

5) Quantified performance guidelines would be provided and utilized in related research activities.

ANGULAR SELECTIVE GLAZING

Objective

This research consists of developing advanced glazing materials which modulate solar transmittance in response to the angular relationship between the glazing and the incident solar flux. The objective is to provide solar transmissions of greater than 90 percent in the desired solid angle of acceptance and rejection of 90 percent of the incident flux outside that region. Examples of materials in this area include: 1) holographic films that collect incident solar flux over a large solid angle and redirect it to a specific region of the interior of the building, and 2) materials in which oriented particulate structures are embedded.

Importance to the Building Industry

The primary applications of angular selective glazing devices are to:

1) Enhance the natural lighting potentials for the aperture by redirecting the incident solar flux to places within the building where illumination is needed

2) Enhance the passive heating potentials of the aperture by redirecting the incident solar flux to absorbent storage materials

3) Rejection of incident solar flux from undesirable regions of the sky.

Improved control over the collection and distribution of solar illumination and energy can extend the effective use of the solar resource from the proximity of the glazing to more remote areas of the building, possibly even to the core zone of commercial buildings, and provide temporal control over solar gains. The effect of this improved control strategy will be to displace conventional fuels for heating and lighting and assist in load management and peak load reduction.

Urgency

Research in this area is important in the long term. While mechanical devices with manual or automated controls can accomplish much of the objective of this research area, their complexity and aesthetic penalties will probably limit their applicability. For this reason, in order to realize the full benefits of angularly selective aperture materials, it is important to undertake materials research and development.

Stage of Completion and Remaining Problems

Light penetration into the interior of buildings can be enhanced by light shelves and reflective devices. The latter devices can also enhance solar heating performance by directing incident solar energy toward localized thermal storage masses. These "manual" angularly selective devices typically have substantial first-cost penalties and long-term reliability uncertainties. To date, little research has been done on aperture materials which would realize the angle selectivity benefits as an inherent material property. Candidate materials, such as holographic films and aligned microstructures, have been postulated but actual research is in its infancy.

Product or Results Required

Research in this area could result in a range of materials that could be incorporated into windows, skylights and other aperture assemblies, as follows:

- Fresnel optical elements and other refractive optical devices that transmit solar illumination and energy to predetermined regions in the building
- Multi-layer holographic films optimized for prespecified regions of the solar spectrum
- Reflective materials incorporating aligned microstructures
- Other novel optical technologies

These research results can be in the form of films, coatings or bulk processes which can be applied to existing glazing or can replace conventional glazing systems. Also included in the results will be appropriate technical and design information relating to material productions and applications as appropriate.

Level of Effort and Time Required

The materials suggested here are in their earliest stages of research. As with any new and innovative glazing materials, the combined R&D time plus the time required to design and establish a production and distribution capability, if warranted by the basic research results, is very long. Given recent experience with low emissivity glazing systems, a total of more than 10 years is estimated before these materials could achieve widespread use. Largely because of the probable need for new production facilities for materials of this type, a total expenditure of more than $10 million probably would be required to achieve widespread use of the proposed materials. The necessary research required to provide the private sector with information on which to base product decisions is estimated to require $3 million over a 5-year time frame.

Methodology -- Most Effective Way to Accomplish Objective

A five-step research program is required:

1) Through systems analysis, characterize the requirements for angular selective materials, establish quantified materials development goals and select leading material candidates.

2) Identify techniques for preparing the subject materials, prepare laboratory samples and test their thermal and optical properties.

3) Through systems analysis, evaluate the materials in terms of total energy impacts for various building types in various climates.

4) Field testing and evaluation.

5) Product planning.

SPECTRAL CONTROL

Objective

To develop advanced optical technologies for the improved selective transmission of the visible spectral portion of solar radiation so that not less than 200 lumens per watt are transmitted and available for daylighting utilization.

Importance to the Building Industry

Lighting uses 25 percent of U. S. electricity and the electrical component of heating and cooling is of great significance in many areas. In commercial buildings, the lighting load may exceed 50 percent of the building's electrical usage and is a major contributor to utility systems peaks. Daylighting strategies that displace electrical lighting and cooling may also assist in peak reduction and load management.

Urgency

In view of the above, this work is considered to be of utmost importance.

Stage of Completion and Remaining Problems

Significant progress has already been made but much work is still required. Films remain to be more exact and selective. The major remaining problem is the deposit of films on large areas.

Products or Results Required

Glazing or glazing with coatings that will have improved selective qualities of reflectance, transmittance, and emission. These could include:

1) Multi-layer holographic films optimized for visible radiation transmittance

2) Reflective materials incorporating aligned micro-structures

3) Coatings to reduce reflections

4) Application of current lamp envelope thin film techniques to glazing.

Level of Effort and Time Required

This work can be accomplished for approximately $5 million and within the next 2 to 5 years.

Methodology -- Most Effective Way to Accomplish Objective

1) Investigation to identify most appropriate materials for spectrally selective glazing systems

2) Properties of candidate materials could be characterized

3) Experimental and theoretical investigations to determine effectiveness of suggested materials and techniques

4) Testing under actual building conditions

5) Quantified performance guidelines could be provided.

ENVIRONMENT AND RESOURCE CHARACTERIZATION

Objective

The objective of this research is to provide usable characterization and/or data describing the environmental conditions as they relate to the thermal and optical performance of apertures. Among the primary issues are:

1) The spectral content and angular properties of the solar resource as a function of time of day, time of year, atmospheric conditions, including degree of cloud cover

2) Sky temperature as a function of environmental conditions

3) The spectral content of radiation from the natural and man-made environment to which the aperture might be exposed.

Importance to the Building Industry

The measurement and analysis program suggested here is necessary in order to reliably determine the thermal and optical characteristics that the designer can most advantageously utilize in a specific application, and to estimate the energy impacts that a specific aperture material will have on a building. The characterizations of the environmental resource are also necessary in order to better define the desirable specifications of innovative new materials.

Urgency

While considerable effort has been devoted to measurement of environmental variables such as ambient temperature and total solar radiation, the development of new glazing technologies that attempt to utilize resources which have been largely neglected to date requires new information about that aspect of the environment. It is, therefore, very important to expand the existing environmental data network so that the existing information

gap can be filled thereby allowing effective use of advanced aperture materials. For efficiency, it is also important to undertake this expansion in a way that makes the large existing data base as usable as possible in determining these "new" environmental parameters.

Stage of Completion and Remaining Problems

As previously stated, there is a large data base on environmental parameters including solar energy availability, wetbulb and drybulb temperature and wind speed and direction. Far more limited data bases on solar illumination availability and sky temperature have also been developed during the past few years. The primary needs at this point are:

1) Expansion of the illumination data base to ensure climate coverage

2) An expansion of the data collection capabilities at selected sites to measure diffuse radiation availability both with respect to energy and illumination

3) An expansion of sky temperature measurements.

These new data should be carefully analyzed in terms of more commonly available parameters in order to characterize the "new" variables in terms of the old, thereby allowing the existing data base to be used to reliably estimate the needed parameters based on historic data.

Products or Results Required

The primary products of the research are: 1) expanded measurement capabilities at existing environmental data collection sites, and 2) expanded data bases extracted from the existing data base from correlations developed from short-term tests. This latter product is very important in order to make the necessary data available on a time schedule consistent with anticipated materials research plans.

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Level of Effort and Time Required

It is estimated that this activity would require $2 million to $3 million over a 4- or 5-year time period. This includes the cost of short-term testing, correlation development and use of the correlations to extrapolate the existing data base to include the new parameters. It also includes the upgrading of existing measurement sites for long-term data collection but does not include incremental operations and data processing costs for those sites.

Methodology -- Most Effective Way to Accomplish Objective

Measurement techniques for the expanded environmental data collection capabilities are largely existing. The following research steps will be required:

- Determination of data collection requirements (parameters to be measured, frequency, accuracy, etc.)
- Instrumentation fabrication, testing and siting
- Short-term data collection (approximately 2 years)
- Short-term data analysis and correlation development
- Processing of historical data using the correlations developed in the above step
- Ongoing long-term measurements

THERMAL AND DAYLIGHTING MODELS

Objectives

To develop and validate a range of required analytical models and experimental techniques to provide the technical basis for determining the energy-related performance of fenestration materials, components and systems, including daylighting effects as well as thermal performance.

Importance to the Building Industry

The classic steady-state engineering perspective concludes that glazing is a significant cost in buildings. However, an annual analysis that properly accounts for dynamic climatic variables such as heat loss, solar gain, natural ventilation and daylighting shows that fenestration can provide net energy benefits if the energy flows are properly controlled. Although it is possible to analyze fenestration by considering the component or system as an isolated building element, this approach can lead to erroneous results because fenestration performance canot be properly understood without considering the coupling to the larger issues of building energy performance. Rational and informed decision making requires the availability of technically sound performance data on fenestration components and systems which, in turn, requires the analytical and experimental tools necessary to derive and/or measure the appropriate data. Prior to our renewed concern for energy efficiency, simple characterization of existing products was adequate. Now, to properly characterize fenestration performance, it may be necessary to know:

1) Thermal conductance under a range of environmental conditions
2) Solar-optical properties for direct and diffuse radiation
3) Air-leakage and ventilating properties
4) The change in these properties as materials are exposed to cyclical weathering effects and aging.

As improved materials and systems such as IR-transparent glazings and heat mirrors are introduced to the marketplace, conventional analysis and testing may be inadequate to provide the information required by decision-makers.

Urgency

Development of analytical models or experimental techniques to characterize materials of fenestration systems is an essential prerequisite to development and use of building energy analysis computer models and to the development of performance data required by the design community. This task thus forms the essential foundation for all other modeling and testing projects.

Stage of Completion and Remaining Problems

There are existing analytical and experimental techniques to determine standard properties of conventional materials. Over the last 5 years, new research efforts have resulted in the ability to better characterize the performance of some passive solar systems and other high-performance window systems. These analytical and experimental approaches must be extended to include newly developed materials and fenestratiion systems and should emphasize prediction of solar heat gain and daylighting effects, which are much less well developed than heat loss modeling.

Products or Results Required

A. Thermal Performance

- o Improved window heat transfer models, including:
  - Edge-frame effects
  - Film coefficient modeling
  - Combined conductive/air leakage effects
  - Sloped glazing effects
  - Solar heat gain model for complex shading systems
  - Experimental validation

B. Daylighting Analysis

- o Develop analytical capabilities to predict illuminance in rooms for a broad range of architectural solutions
- o Develop analytical capabilities to predict electric lighting energy consumption based upon control strategy, climate and architectural design
- o Develop techniques to assess discomfort glare and lighting quality for daylighted interiors
- o Validate analytical models using outdoor scale model tests and indoor sky simulation testing
- o Develop the capability for analyzing daylighting impact of any design in building energy analysis programs
- o Develop techniques to characterize the luminous transmittance of materials and components.

Level of Effort and Time Required

This task would be an on-going task over a 5- to 10-year time frame and requiring approximately $1-$2 million per year over this time period.

Methodology -- Most Effective Way to Accomplish Objectives

Analytical and experimental models often represent complementary approaches to development of a capability for characterizing fenestration performance. Some problems, for example, solar heat gain through multiple glazing systems, can be solved entirely by relying on analytical solutions (although all computer models should be experimentally validated). Other problems (e.g. daylight illuminance from complex fenestration system) might best be solved using scale model techniques. Both the daylighting at thermal models described above must be developed and validated, e.g. so that solar gain at related daylight transmittance data are obtained on a comparable basis. The basic modeling requirements listed above are minimal requirements - a number of specific models may have to be developed in a single area.

FENESTRATION ENERGY ANALYSIS AND FIELD TESTING

Objectives

1) To develop the technical basis for integrating thermal and daylighting performance issues of fenestration into the performance of envelope systems using energy analysis models. This includes all technical performance attributes such as heat loss, heat gain, thermal mass, infiltration, natural ventilation, daylighting, as well as other performance issues (e.g., condensation).

2) To develop optimal fenestration solutions as a function of building type (residential, non-residential, new/retrofit) climate and operation using parametric studies.

3) To develop a data base on fenestration performance by performing experimental studies in test buildings and in controlled field test facilities to validate computer models of component and fenestration system performance and of optimized design strategies.

Importance to the Building Industry

Historically, fenestration has been used almost solely as an occupant amenity, as a code-required source of minimum outside air and light, as emergency egress and as a design element to enhance the appearance of the building. It has been assumed and designed to be a net energy loser. Fenestration accounts for about 5 percent of total U. S. energy consumption. The traditional perception of fenestration as an energy cost can be reversed to become an energy source if the energy flows across the fenestration interface can be properly controlled. If each fenestration element can provide net useful energy to the building, or at least consume zero net energy, they should outperform most insulated walls and roofs. Thus, the integration of fenestration into the building envelope may suggest radical departures from traditional solutions. While the use of solar gain in residences from south orientations has been extensively explored, fenestration impact on non-south orientations and in all orientations in non-residential buildings are not as well understood. Proper integration requires

that analytical models be available for comparing the performance of various integrated strategies. These models are in varying states of development and validation.

Data collected from field testing of fenestration systems is essential to develop a better understanding of fenestration performance as a function of building types, orientation and climate. The key to optimizing aperture performance is to develop products and design solutions that respond favorably to a wide range of conflicting environmental forces. For example, a high transmittance window system designed to admit solar gain in winter will produce unacceptable cooling loads if not properly shaded in summer. Annual energy consumption is normally estimated from calculations that rely on calculated or measured values of fenestration properties. These values are typically steady-state values determined under simplified conditions. They may be useful for limited comparisons between products, as an indicator of product quality, or as a measure of product performance under extreme conditions but they are often a poor indicator of net annual energy performance. Furthermore, it is well known that fenestration performance may be strongly coupled to building parameters such as thermal mass, installed lighting levels, or night setback strategies and these effects are frequently overlooked in simplified calculations or laboratory testing. Even the computer codes used to determine annual performance all include simplifications to reduce the cost and complexity of calculations. It is important to have a base of measured performance data against which specific algorithms can be validated and to calibrate the overall performance predictions. Construction quality and occupancy effects are rarely accounted for in most computer models and introduce additional uncertainty in performance estimates. These effects can also complicate interpretation of results from field measurements so it is essential to have a field measurement capability that properly accounts for the fenestration/building/environment interactions but allows discrimination between intrinsic component performance issues. These studies would be conducted in carefully selected buildings and in outdoor test chamber facilities.

Urgency

Proper design and integration of fenestration has a major impact on total building energy consumption in many direct and indirect ways. In addition to direct energy use, thermal and visual comfort, view, noise and other factors are all elements of fenestration performance. The potential savings that might be achieved are enormous since well designed fenestration can not only reduce energy requirements, but can provide an energy resource to the building in the form of heat and light. This task provides the technical basis for design data required by the building community.

Stage of Completion and Remaining Problems

Previous research efforts have resulted in general energy analysis models which provide a basis for these analytical studies. These models must be extended to include additional modeling capabilities for daylighting prediction and for overall performance of advanced fenestration systems. Field validation of individual algorithms and of overall performance predictions is at a very early stage and must be emphasized if the energy analysis models are to be used with confidence by the building community. Limited parametric studies using early versions of an energy analysis model has been completed but more systematic and extensive studies are required.

Products or Results Required

1) Validated tools to analyze and predict the thermal aspects of fenestration component performance (daylighting predictive tools are mentioned in 2.4 and 2.6).

2) Validated tools to analyze and predict total fenestration performance in the context of the building envelope for all building types and climates.

3) Guidelines and strategies for development of optimal fenestration systems which minimize energy consumption, peak load impact, and other energy-related costs.

4) Development field test facilities to measure fenestration performance and development of techniques to determine in-site performance in buildings.

5) Documentation of performance results from field test facilities and measured buildings.

Level of Effort and Time Required

This task requires a sustained effort of moderate size ($2 million to $3 million per year over a 5- to 10-year period in order to provide the information required by the building community for both existing and novel fenestration systems.

Methodology -- Most Effective Way to Accomplish Objectives

Three parallel activities are required to accomplish the stated objectives:

1) Existing energy analysis models must be expanded to include a more extensive and detailed modeling capability for existing and advanced fenestration systems, modeling both daylighting and thermal effects.

2) Appropriate field test capabilities must be developed and utilized to provide the detailed performance data to validate and extend the computer models.

3) The validated energy analysis models will be used for an extensive series of parametric studies for all building types and climates to develop a performance data base from which simplified design data and simplified models can be developed. Results from fuel test cells and building monitoring are essential to provide confidence on these analytical tools. The most useful and cost effective results will emerge from a balanced program with all of these major elements.

DESIGN INFORMATION

Objectives

To produce a catalogue of generic aperture design strategies which classifies types of systems and their thermal and visual characteristics and performance (output of first six research topics on aperture systems). This must include complete documentation on quality (as well as quantity) of resulting interior environments under different climate conditions.

To produce 1) design guidelines on performance "rules of thumb"; and 2) simplified performance estimating procedures for aperture strategies (must be able to relate this to overall building energy performance).

Importance to Building Industry

Critical to improve design process which could have a subsequent impact on the construction of new buildings.

Urgency

Quality and form of information can have major impact on extent of use in design process.

Stage of Completion and Remaining Problems

Design information is being continuously generated by all research efforts and is one of the important on-going products of programs. However, careful organization of information for designers is in the very earliest phases and needs major attention. At present, most of it is in piecemeal form.

Products or Results Required

- o Catalogues and/or manuals
- o Design guidelines for performance
- o Sample estimating procedure, hand calculation as well as software, etc.

Level of Effort and Time Required

"On-going" over 10 years at a cost of $10 million plus.

Methodology -- Most Effective Way to Accomplish Objectives

- o Conduct analysis to determine best form of information for different users, architects, engineers, builders, developers, etc.
- o Develop analysis, classification and graphic representation of generic types in conjunction with designers
- o Test and evaluate usefulness of information and design tools in design situations (Can the tools really be used by designers? Do they reveal important potential strategies? Do they address the right questions?)

COMPONENT AND SUBSYSTEM RESEARCH

PANEL IC: VENTILATION, INFILTRATION, MOISTURE CONTROL AND INDOOR AIR QUALITY

Introduction

Group IC discussed ventilation research issues that will lead to reduced energy use in buildings. Conditioning and mechanically moving the air in buildings requires energy. Strategies to reduce energy consumption often focus on some procedure to reduce ventilation. However, first we must understand the implications of ventilation changes on air quality within the buildings under consideration. Since ventilation is important for removal of air contaminants, reducing ventilation without changing the pollutant sources within the space may cause a degradation in air quality sufficient to cause significant risk to building occupants.

Our understanding of the interrelationships among indoor air quality, ventilation, and removal rates is relatively modest. Issues requiring attention so that we can confidently specify a healthful indoor environment that will not be jeopardized by reduction in ventilation rates are discussed in Task 1, Indoor Air Contaminant Sources and Characteristics; Task 2, Observed Concentrations; Task 3, Personal Exposures to Contaminants; Task 4, Health Effects Issues; and Task 5, Control of Indoor Contaminants. The mechanisms and procedures than need to be examined in achieving a balance between energy savings and health and comfort issues include Task 6, Infiltration and Air Leakage; Task 7, Natural Ventilation; and Task 8, Mechanical Ventilation.

Moisture within buildings is a special case of the indoor contaminants referred to above. While a minimum amount of moisture is necessary for the health of building occupants and protection of furnishings and building materials, excessive amounts can contribute to health problems, energy waste, and structural problems such as mildew, wood rot, and degradation of insulation performance. For these reasons, a separate task, Task 9, Moisture Migration and Control, is included in our list of research tasks of importance.

Our task group was polled to develop a consensus concerning several general issues that describe each of the tasks. Our descriptions of the current stage of completion of each task, the level of effort and time required, the most effective type of research needed, and our perception of the tasks urgency are shown in the figure below.

SUMMARY OF THE BUILDING ENERGY RESEARCH WORKSHOP

	STAGE OF COMPLETION			ANNUAL LEVEL OF EFFORT			TOTAL LEVEL OF EFFORT			TIME REQUIRED			MEANS OF ACCOMPLISHMENT			URGENCY OF ACTIVITY		
	IN EARLY STAGE OF DEVELOPMENT	SIGNIFICANT PROGRESS ALREADY MADE, MUCH MORE REQUIRED	QUITE CLOSE TO COMPLETION	$1 MIL OR LESS	$5 MIL	$10 MIL OR MORE	$1 MIL OR LESS	$5 MIL	$10 MIL OR MORE	2 YEARS OR LESS	3-7 YEARS	10 YEARS OR MORE	GENERIC RESEARCH, ANALYTICAL MATERIAL AND TECHNICAL SCIENCES, ETC.	APPLIED RESEARCH COMPONENT/PRODUCT DEVELOPMENT	FIELD TEST, VALIDATION AND DEPLOYMENT	CRITICAL	IMPORTANT	MINIMAL
INDOOR AIR CONTAMINANT SOURCES AND CHARACTERISTICS		•		•				•			•		•	•	•			
OBSERVED CONCENTRATIONS	•				•				•		•			•	•		•	
EXPOSURE STUDIES	•			•				•			•			•	•		•	
HEALTH EFFECTS ISSUES		•		•					•			•	•	•	•	•	•	
CONTAMINANT CONTROL STRATEGIES		•			•				•		•			•	•	•	•	
INFILTRATION AND AIR LEAKAGE			•	•			•			•								•
NATURAL VENTILATION TO REDUCE AIR CONDITIONING ENERGY USE		•			•			•			•			•	•		•	
MECHANICAL VENTILATION		•		•				•			•			•	•		•	
MOISTURE MIGRATION AND CONTROLS			•	•			•			•				•	•			•

1C COMPONENT & SUBSYSTEM RESEARCH
VENTILATION, INFILTRATION, MOISTURE CONTROL & INDOOR AIR QUALITY.

INDOOR AIR CONTAMINANT SOURCES AND CHARACTERISTICS

Objective

Characterize indoor air contaminant sources. Determine physical and chemical properties of sources to aid development of control mechanisms of indoor air pollution.

Importance to Building Industry

Liability problems may occur for builders of homes with indoor air pollutant problems, even where the structure is not the major source of indoor air contamination, a fact that would need to be proven. Builders need to be able to select building materials and heating systems and construction techniques that maximize thermal integrity and energy efficiency, without endangering the health and safety of occupants. Safe exposure to indoor air pollutants should be assured for occupants of existing homes at reasonable cost and convenience.

Recent assessments of the Indoor Air Quality issue have been performed by the National Academy of Sciences, ASHRAE, the World Health Organization, the Council on Environmental Quality, the General Accounting Office, and other organizations. There exists complete agreement that the area is one of major significance to the building industry and to public health. A workshop of Federal and industry participants held in December 1980 reached a similar conclusion and began to develop a research agenda.

Urgency

See introductory figure. If ventilation reductions can lead to substantial energy savings, then our understanding of indoor air quality is critical to achieving these savings.

Stage of Completion and Remaining Problems

A major component of exposure to air pollution is the exposure in the indoor environment. The establishment of cause and effect relationships between exposure to air contaminants and potential health effects begins with the identification of the contaminant sources. Identification and characterization of contaminant sources in the indoor environment is difficult due to the plurality of potential sources, the complexity of emission mechanisms operating, and the potential of multiple sources emitting the same contaminant simultaneously.

Preliminary research identifies four general sources of air pollutants:

1) Occupant activities (cleaning, cooking, smoking, etc.)

2) Appliances (incomplete combustion sources)

3) Materials (outgassing from furnishings and building materials)

4) Outdoor pollution (introduced with ventilation air).

Emissions from the third category are of direct concern to the building industry. Emissions from the first group may pose the greatest problem. Presently, control technologies applied are either ineffective or prohibitively expensive.

Products or Results Required

- A complete list of indoor pollution sources
- Emission rates of major sources for each pollutant emitted under a variety of environmental conditions
- Tabulation of the physical, chemical, and biological properties of air contaminants that directly impact the pollutant concentrations and consequently the potential health effects and required controls.

- o Determination of source control technologies (if necessary) and quantification of their ability to reduce emission rates

- o Formulation of an emission contribution rating system, or guidelines with exemplary calculations, charts, and monographs to estimate the impact on indoor air quality of indoor sources operating individually or in conjunction with others.

Methodology -- Most Effective Way to Accomplish Objectives

A three-step research program should be followed:

1) Laboratory studies (chamber or well-controlled residential experiments)

2) Field studies (measurements under "real-life" conditions)

3) Model formulation (to extrapolate research findings) and establish parameter relationships).

Experimental protocols involving engineering and statistical designs must be formulated and followed at each stage of implementing the research process. Instrumentation requirements should also be addressed.

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OBSERVED CONCENTRATIONS

Objective

To define indoor air quality concentrations in existing housing and building stock, in order to determine the distribution of concentrations.

Importance to the Building Industry

These data are of fundamental importance to consumers and the industry. Without information on existing Indoor Air Quality from representative samples of indoor environments for a variety of geographic and demographic sub-groups, we have no basis for determining the magnitude of the potential problem. Sharper definition would permit contaminant priority setting and help to specify effective mitigation strategies.

Consumers would directly benefit from the identification of sources, location and conditions associated with healthful and unhealthful Indoor Air Quality. To the degree that occupant choices affect sources, ventilation and controls-improved Indoor Air Quality may be achieved by consumer preference. This will not be the case for all contaminants or in all locations. However, research priorities for both public and private action would be assisted by scaling the level of effort required by the number of people exposed, hazards associated with exposure, locations of exposure and relationship betweeen emissions and ventilation.

Stage of Completion and Remaining Problems

To date, our knowledge of indoor air quality has been obtained from relatively few studies that have been conducted under different protocols. These studies do not constitute a representative sample of the housing and building stock in the U. S. Further, the experience with tightly constructed houses has been limited to experimental buildings. In many studies, parameters relevant to understanding the interactions among ventilation,

sources, removal terms were not determined. These deficiencies limit the usefulness of the existing data in determining populations at risk, the relationship between indoor air quality, sources and ventilation.

Products or Results Required

- Distribution of contaminant concentrations (considering the sampling integration time appropriate to the response variable of interest) by building type for several contaminants.
- Identification of sources/contributions to indoor concentrations.
- Identification of population, locations, sources at or contributing to higher risk groups.
- Identification of factors (ventilation, sources, design, behavioral) that influence indoor concentrations.

Level of Effort and Time Required

(100 x 10^6 structures) x ($100/structure) x (0.1 percent sample) implies a $10 million effort. In addition, we need a national center for designing, archiving, and analyzing data obtained by a number of cooperating research groups.

Methodology -- Most Effective Way to Accomplish Objectives

- A sample survey would have to be carefully designed to obtain a statistically valid sample. There are numerous variables to be considered across many classifications of indoor environments. Considering that a number of contaminants would be investigated, this nationwide survey would be a major undertaking. A coordinating function for funding, sampling protocol, data archiving should be maintained at a prominent national level while research could be conducted at a local level by universities and research groups.
- Develop simple instrument packages for several contaminants and tracer gases. A tracer gas is necessary for determining ventilation rates at the time of sampling.
- [illegible] a national data bank for storing and analyzing [illegible].

PERSONAL EXPOSURES TO CONTAMINANTS

Objective

To determine the contribution to individual and population exposures of contaminants encountered within building environments relative to those encountered elsewhere, such as the outdoors, at work, school or during transport.

Importance to the Building Industry

Various measures have been recommended to conserve indoor consumption of energy. Among these measures are those that may result in high levels of various contaminants. Before setting standards and regulations to control the sources of indoor contaminants and before indoor air quality control methodologies are developed and used to limit individual exposure to these contaminants, it is important to put into perspective the relative pollutant burdens to which individuals are exposed from indoor environments versus those to which they are exposed from other sources. According to the National Research Council on Indoor Pollutants, "this knowledge is a prerequisite to rational allocation of resources for warranted reductions in population exposures."

Urgency

We believe that these studies are critically important and should proceed alongside source characterization studies. Initially, they would address well-known contaminants such as CO and NO_x.

Stage of Completion and Remaining Problems

- The Gas Research Institute plans to initiate a CO, NO_x exposure study at Harvard University.
- EPA has initiated a study with PEDCO to examine public exposure to CO.

- EPRI has initiated a program with Columbia University to study the exposure of asthmatics to NO_2 in New York City.

Parallel studies should be initiated for radon and formaldehyde and later for other contaminants of concern.

Products or Results Required

The output of exposure studies is the identification of pollutants to which the public is exposed which are primarily attributable to indoor sources. Once these are identified, rational standards and regulations and/or cost-effective control techniques may be developed to minimize public exposure to these emissions.

A secondary output will be the development of personal monitors and instrumentation that may be used in other applications such as the sensors in responsive control devices.

Level of Effort and Time Required

A level of effort of $5 million, 25 to 30 person-years, and a duration of 3 to 7 years to completion is anticipated.

Methodology -- Most Effective Way to Accomplish Objective

- Select pollutants for exposure studies and determine sensitivity and accuracy criteria for measurements to be made.
- Evaluate available instruments.
- Develop personal sampling instruments as needed.
- Design protocol of exposure study from a statistical standpoint, taking into account people's activities, sources, source usage, activity patterns, demographics, etc.
- Conduct exposure study.
- Analyze data and develop rating system for pollutants of concern (see Task 1, "Sources and Emission Characteristics").

HEALTH EFFECTS ISSUES

Objectives

There is a general need to obtain more accurate information on the "health effects" of indoor contaminants. These investigations would help define the effects end points specific to a contaminant, exposure characteristic (i.e., acute versus chronic, frequency and magnitude of exposure), and sensitive population (i.e., children, asthmatics, elderly).

Importance to the Building Industry

Information that would permit a more precise definition of healthful air quality is of fundamental importance to the industry and to occupants of buildings. This information would input into standards (guidelines) for acceptable IAQ which would permit the identification of high-risk populations, and the design of ventilation and control equipment.

Stage of Completion and Remaining Problems

Evidence for health effects associated with indoor contaminant exposure is diffuse. Much of what we know about health effects of contaminants found indoors comes from occupation studies, controlled chamber exposure studies and, to a lesser extent, animal and bacterial bioassays. This evidence is of limited use when attempting to define the level of healthfulness for indoor air. There is information to suggest that subtle non-symptomatic effects or chronic effects are possible at exposure levels now documented in many indoor environments. Further, the question of sensitive individuals who manifest irritation to very low levels of indoor contaminants must be considered.

Products or Results Required

- Exposure-response curves specific to a contaminant and population group (normals, elderly, asthmatic, chemically sensitive)
- Develop bioassay screening test for sources
- Improve basic understanding of the bio-chemical mechanisms governing the toxicology of environmental pollutants.

Methodology -- Most Effective Way to Accomplish Objective

Some pollutants need to be studied with epidemiology while others will require detailed basic research on their biochemical effects.

- Epidemiological investigations that will help to define the magnitude of response to indoor pollutants. A prospective case control study on predetermined high-risk groups may be the preferred approach.
- Bioassays (animal and bacteria) to develop a relative toxicity ranking for emissions sources or for indoor contaminant mixtures.
- Clinical exposure studies to identify irritation, neurotoxicological and physiological effects of short-term subsymptomatic exposures to gases and particulate mixtures found indoors.
- Case-study examination of infectivity of contact contagens and aeropathogens to understand the influence of infiltration and ventilation on the incidence of acute respiratory disease.

CONTROL OF INDOOR CONTAMINANTS

Objective

To determine energy efficient, reliable, and cost-effective techniques to control and/or remove contaminants from indoor air.

Importance to the Building Industry

An estimated large market for control equipment should be available once pollution level guidelines are set and suitable equipment and systems are developed. This may also relieve manufacturers, designers, and others from many potential lawsuits.

Urgency

Economics has already driven the use of lower ventilation rates and may result in exposing large numbers of people to real long-term health risks. Urgency is critical.

Stage of Completion and Remaining Problems

Many strategies are known, but cost-effectiveness has not generally been demonstrated. Lack of sensors is critical.

Once contaminant levels have been set, components and systems must be designed for both new and retrofit applications. Three known methods are available to reduce contaminants:

1) Dilution with less contaminated air from outside the space by mechanical methods (infiltration and natural ventilation are covered elsewhere).

2) Control of the contaminant at or near its source by containment or local exhaust, or by removing or banning the source.

3) Removal of the contaminant from the air by mechanical or other means within or near the space without replacing the air.

In 1), outside air might be introduced and suitably mixed in the space through a regenerative heat exchanger, if cost-effective. Pollutant carry-over, moisture, and defrost service life, maintenance and cost are examples of research needs as well as application guidelines for location of air paths in application. In addition, to ensure adequate mixing or non-mixing air in the space, system guidelines need development. This is also true for items 2) and 3). Contaminant sensors for control are also needed to minimize energy use in 1), 2), and 3) which are specific to the contaminants of interest. Moisture is included in 2). Design guidelines for system applications are needed as well as cost-effective hardware designs.

Research and development on barrier techniques are also needed. In 3), development of removal equipment (filters, absorbers, etc.) is needed, although direct removal such as by electrical space charging should be investigated. Standard evaluation methods for all equipment except for particle removal are needed. Special situations, such as garages, etc., may need special equipment.

Products or Results Required

Cost-effective sensors, devices, systems and application guidelines, with practical performance standards to support their efficiency.

Methodology -- Most Effective Way to Accomplish Objectives

A broad range of sensor technology and contaminant control/removal technology development is required. This work must be supported by standard development and demonstration in a wide variety of residential and commercial applications to verify their efficacy. Fundamental research on transport mechanisms within spaces is also needed.

INFILTRATION AND AIR LEAKAGE

Objectives

To develop means to reduce heating and cooling loads for buildings by eliminating the unintentional flow of outside air into buildings, so that either controlled ventilation or minimal infiltration can maintain an acceptable indoor environment.

Importance to the Building Industry

Infiltration traditionally has been a major component of energy use in buildings. Thus, reducing air infiltration is a primary strategy to save energy. For residences, builders have responded, and are constructing tighter buildings. These tighter buildings raise questions of indoor air pollution, moisture damage, and associated safety hazards and liability concerns. A thorough understanding of the air infiltration rate in residences is, therefore, quite important.

For existing buildings, reducing air infiltration has been a primary goal for occupants and homeowners. Forty-one percent of those claiming tax credits invested in caulking or weatherstripping. However, these attempts have often been ineffective, because many sources of air leakage have been undetected. For homeowners of existing buildings, infiltration remains a paramount problem. In commercial and industrial buildings, infiltration rates are unknown, and designers and building operators often choose to pressurize the building via the ventilation system, causing excessive energy consumption, not only because of the need to warm the incoming air, but increasing the fan power (necessary for pressurization) as well.

Stage of Completion and Remaining Problems

Infiltration traditionally has contributed one-fourth to one-third of the heating and cooling loads in residences, and an undetermined portion

(probably 15 percent) of the heating and cooling load of commercial buildings. The amount of infiltration is a function of the design and construction quality of the building envelope and mechanical systems, the building occupant activities, and the weather and local topography. There are techniques for designing tight buildings, and a small percentage have been constructed to limit infiltration to 0.1 air changes per hour. For existing buildings, retrofit techniques are complicated by the need to determine the locations of the major air leakage sites. In industrial and commercial buildings, there is a paucity of data on air infiltration rates. Locating the sources of air leakage in commercial and industrial buildings is a virtually unexplored research area.

Products or Results Required

- Instruments to find air leakage sites and to determine air infiltration rates
- Validated predictive models for determining likely air infiltration rates
- Guidelines and design manuals for minimal air leakage in new construction, retrofits, and renovations
- Performance standards/guidelines on air tightness of buildings (e.g., using pressurization techniques).

Methodology -- Most Effective Way to Accomplish Objective

- Improve instrumentation techniques for determining air infiltration rates in large buildings. Improve instrumentation techniques for determining long-term infiltration rates in all buildings. Improve instrumentation techniques for determining air tightness of buildings (e.g., pressurization techniques at pressures the building experiences).
- Measure a substantial number of large buildings to determine ventilation and infiltration rates. Use infrared techniques to locate reasons/locations for air leakage.
- Develop predictive techniques for determining (approximating) air leakage rates of building prior to construction.
- Develop improved techniques for retrofitting existing buildings to improve their air-tightness. Transfer the technology to private sector.

NATURAL VENTILATION

Objectives

Develop low cost experimental techniques to evaluate ventilation designs and develop computer models to predict energy savings from ventilated buildings.

Importance to the Building Industry

Currently, natural ventilation is rarely specified for reducing air conditioning energy use because a quantitative basis for design does not exist. In the South, between 30 percent and 50 percent of the air conditioning energy use in homes can be saved by natural ventilation. Similar savings may be achieved by night ventilating massive office buildings. A rational basis for design will thus encourage architects and homebuilders to include natural ventilation as a building conditioning option.

Products or Results Required

- o Low-cost test methods utilizing small-scale models tested in the natural wind for evaluating ventilation designs. Such methods should be usable by architectural and design firms directly.
- o Validated building energy analysis computer programs which can predict energy savings from naturally ventilated buildings.

Methodology -- Most Effective Way to Accomplish Objective

1) Develop validated outdoor small-scale test methods.

2) Develop algorithms to predict air flow through multiple building zones as a function of building shape, window placement, neighboring buildings, site terrain and wind turbulence as well as mean speed and direction. This task includes a comprehensive data base development on building pressure distribution and an investigation of the applicability of solid building pressure distribution data to ventilated buildings.

3) Algorithms to determine room internal surface convective film coefficients of naturally ventilated rooms.

4) Algorithms to predict moisture absorption/desorption characteristics of building materials.

5) Full-scale experiments to validate 2, 3 and 4 above for massive night-only ventilated buildings and permanently ventilated buildings.

6) Determine through experiments the upper limits of humidity and air motion allowable indoors using constraints imposed by human comfort, productivity, mold growth, electronic equipment operation, etc. In particular, examine rigorously whether the ASHRAE comfort standard can be extended to higher humidity levels if higher room air velocities are allowed.

MECHANICAL VENTILATION

Objectives

To develop the data necessary to ensure acceptable indoor air quality, with minimum expenditure of energy, by mechanical delivery and control of the optimum air flow quantity, delivery conditions and distribution to the space under consideration. The delivered ventilation air might be outside air, recirculated air that has been "cleaned" or a mixture of these two.

Stage of Completion and Remaining Problems

There is a need for research and development in both the commercial and residential building sectors and consideration should be given to both the new construction and existing building segments of the market.

- Commercial Applications

Mechanical ventilation air delivery is commonly used in commercial applications for the purpose of maintaining indoor air quality at an acceptable level, and is also often used to provide "economizer" cooling when outdoor conditions permit. The current ventilation standards have been established based on application experience with primary emphasis on application activities, odor levels, cigarette smoke, etc. Today there is an inadequate understanding of the technology necessary for optimization of mechanical ventilation from the standpoints of energy impact versus the control of concentration levels of the various contaminants that impact on air quality. In general, it is judged that current ventilation standards dictate excessive air quantities and energy, but there are few research results to substantiate this conclusion. When ventilation air flow is reduced to achieve energy conservation, there is a lack of fundamental knowledge regarding the factors that must be considered to ensure safe/healthful/comfortable conditions in the occupied space.

- Residential Applications

In residential applications up to this time, space ventilation requirements have generally been satisfied by the uncontrolled admission of outside air by infiltration and natural ventilation (windows). In most cases, ventilation air quantities are highly variable and excessive and bear little relationship to the application need. Excessive energy consumption is associated with this infiltration and it is estimated that one-fourth to one-third of the residential heating and cooling loads are due to infiltration.

Current emphasis on residential energy conservation has resulted in substantial efforts to reduce infiltration of outside air, in some cases to a dramatic (hazardous) degree. This is true in both new construction and in existing homes and gives rise to a serious concern as to the uncontrolled impact on space air quality and human safety, health and comfort. The concern has been amplified by an increased awareness of the wide range of pollutants generated in the living environment due to materials, equipment operation, human activities, etc. In addition, the impact of low infiltration on space humidity levels is of concern because of possible deterioration of building materials and furnishing, and impacts on comfort and health.

As in the commercial building applications, these concerns give rise to the need for an improved understanding of the interrelationships among the various residential system control strategies, indoor air quality and energy use.

Products or Results Required

Practical consideration and development of optimized mechanical ventilation systems requires significant advancement in the state of knowledge in order to ensure energy effectiveness, human safety, health and comfort. Ventilation system research is required to complement efforts on pollutants and health/safety/comfort effects. This research should include the development of system modeling/simulation techniques, consideration of alternative system design/control strategies and development of air quality sensors for those contaminants identified as critical in other task studies.

Methodology -- Most Effective Way to Accomplish Objectives

A preliminary listing of required research related to mechanical ventilation control is as follows:

- Survey of existing and new buildings to ensure an accurate data base relative to important parameters.
- Development of comprehensive modeling techniques to establish system relationships as they impact on air quality and energy. Investigate and identify critical problem areas and control options. (Note: Modeling inputs are required from pollutant research efforts.)
- Conduct field studies in conjunction with modeling studies to ensure consistency of results and conclusions.
- Development of practical, accurate, and fast measurement techniques for laboratory and field monitoring of various pollutant concentrations.
- Assess field and modeling findings to identify critical areas of pollutant concern and define control criteria.
- Develop air quality sensors for application in optimized ventilation control.
- Identify prototype systems for field investigation, including consideration of the following:
  - Air-to-air heat exchangers
  - Contaminant pollutant removal techniques
  - Humidity control
  - Odor control
  - Economizer cooling
  - etc.
- Prototype system developments.
- Field applications/demonstrations/validation.
- Product development (as required).

MOISTURE MIGRATION AND CONTROL

Objectives

To understand moisture migration mechanisms and control strategies well enough to prevent structural damage and performance degradation of building materials without major energy performance penalties.

Importance to the Building Industry

Moisture migration may thwart the best intentions of designers and builders by affecting energy efficiency and thermal comfort. Testing of construction techniques and retrofit techniques is needed. Liability of builders, roofers, and vapor barrier manufacturers associated with moisture damage is a significant concern. Understanding the accumulated effect of inter-related design decisions can help optimize energy efficiency and minimize the instances and costs of measures that may counter each other.

Stage of Completion and Remaining Problems

In wood, moisture levels above 20 percent can cause rot, reducing the useful life of wood structures. These moisture levels have been found in many walls and attics, due to improper sealing (e.g., infiltration into cavities) or because of the failure or lack of a vapor barrier. Moisture in insulation materials seriously reduces its effectiveness. The addition of insulation may aggravate moisture problems. Measurement of moisture levels in materials is difficult; one-time measurements generally can not be extrapolated to provide information concerning long-term levels. In practical terms, the prevention of moisture migration in existing homes remains difficult, if not impossible. In addition, the relationship between humidity and comfort needs to be further explored to determine if the use of elevated humidity allows lower temperatures and a savings in energy (as is commonly believed by practitioners).

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Products or Results Required

- Instrumentation to determine moisture levels (in situ) in insulation and wood products.
- Determination of impact of wall retrofits on moisture levels in walls and the impact, if any, on energy requirements to assure occupant comfort.
- Determination of ventilation needs to control moisture in occupied spaces and attics, and the energy impacts, if any, of the ventilation requirements.
- New retrofit techniques to reduce moisture migration.

Methodology -- Most Effective Way to Accomplish Objectives

- Development of instruments and measurement techniques to determine the level of moisture of in situ building materials, especially insulation.
- Determination of attic ventilation rates and their relationship to attic moisture levels and energy efficiency.
- Determination of the efficacy of vapor barrier paints.
- Determination of degradation of insulation performance with increased moisture content.
- Development of construction guidelines to control moisture migration in existing buildings.

WHOLE BUILDING PERFORMANCE RESEARCH
PANEL IIA: RESIDENTIAL AND OTHER SMALL BUILDINGS

Introduction

This group was concerned with improving the energy efficiency of homes and small commercial buildings. In our work, we assumed that materials, component and application research issues were addressed by other working groups. We further assumed that technology transfer program needs and the need to address barriers in the way of implementing innovative energy technologies were also addressed by other groups.

Current needs and the needs of the foreseeable future indicate the need to consider energy issues in the context of a building as a total system around three major activities:

1) Performance monitoring and evaluation

2) Design tool development and their distribution to the target audience

3) Performance prediction

In addition, research needed includes the following:

4) Development of indices for building energy performance

5) Occupancy-related issues

6) Operational strategies for buildings as energy systems

7) Continual assessment of future building energy needs to guide long-term research and the identification of needed research priorities

8) Information dissemination (both technical and non-technical).

A first cut of some of the specific activities the group considered important is represented by the following pages, followed by the group's ratings on relative priorities.

It is important to note the following:

- These research subjects are those that the group had time to consider. They may not present the total picture of needed activities.
- The relative importance between these activities and those considered by other working groups is yet to be addressed.
- All references to cost/benefit analysis imply the consideration of installed features of systems, i.e., the need to conduct industrial engineering studies on total building systems.

These recommendations are not yet a program plan, nor do they represent an exhaustive list of tasks a national program plan must consider. There is a need for an on-going industry-government planning and review process through which a national building energy R&D agenda is developed and updated, and which addresses the following issues:

- Who does what in the public and private sectors?
- What resources and funding are required?
- How is funding distributed?
- How is the conduct of program activities paced?

SUMMARY OF THE BUILDING ENERGY RESEARCH WORKSHOP

	STAGE OF COMPLETION			ANNUAL LEVEL OF EFFORT			TOTAL LEVEL OF EFFORT			TIME REQUIRED			MEANS OF ACCOMPLISHMENT			URGENCY OF ACTIVITY		
	(1) EARLY STAGE OF DEVELOPMENT	SUBSTANTIAL PROGRESS ALREADY MADE, MUCH MORE REQUIRED	QUITE CLOSE TO COMPLETION	$1 MIL OR LESS	$5 MIL	$10 MIL OR MORE	$1 MIL OR LESS	$5 MIL	$10 MIL OR MORE	2 YEARS OR LESS	3-7 YEARS	10 YEARS OR MORE	BASIC RESEARCH AND THEORETICAL RESEARCH, ETC.	APPLIED RESEARCH, COMPONENT/PRODUCT DEVELOPMENT	FIELD TEST, VALIDATION AND DEVELOPMENT	CRITICAL	IMPORTANT	MINIMAL
SOLAR HVAC SYSTEMS		•			•				•		•		•	•			•	
HEAT TRANSFER PHENOMENA		•		•					•			•	•				•	
PERFORMANCE INDICES		•		•				•			•			•		•		
PERFORMANCE PREDICTION		•		•				•			•			•			•	
RESIDENTIAL BUILDINGS MICROCLIMATE EFFECTS	•			•				•				•	•				•	
OCCUPANCY		•		•					•		•				•		•	
DESIGN TOOLS		•		•				•			•			•			•	
LONG-TERM NEEDS ASSESSMENT	•			•				•				•	•				•	
CONVENTIONAL HVAC SYSTEMS		•		•					•			•		•			•	
CONTROLS FOR RESIDENTIAL AND SMALL COMMERCIAL BUILDINGS		•		•				•			•			•			•	
RETROFIT ENVELOPE STRATEGIES		•		•					•			•		•			•	
RETROFIT EQUIPMENT STRATEGIES FOR RESIDENTIAL & SMALL COMMERCIAL BUILDINGS		•		•				•					•				•	
PERFORMANCE EVALUATION AND MONITORING		•		•					•		•				•	•		

2A WHOLE BUILDING PERFORMANCE RESEARCH
RESIDENTIAL & OTHER SMALL BUILDINGS

SOLAR HVAC SYSTEMS

Objective

To develop efficient solar energy systems that will reduce the consumption of conventional fossil fuels and lower peak utility loads.

Importance to the Building Industry

While present energy conservation practices combined with efficient equipment have proven to be effective in reducing annual building heating requirements, their effect on annual cooling loads is limited, particularly in new construction.

As older buildings are replaced with new construction, annual building energy consumption for a large part of the Nation will become more heavily cooling dependent. Further research and development in solar cooling will establish the technical base needed to develop efficient solar cooling systems at competitive prices.

Urgency

This is a very urgent need, especially when current demographic trends are considered. Americans are on the move toward more temperate climates. As a consequence, within the next two decades, the majority of new buildings will be constructed in cooling load dominated southerly regions.

Stage of Completion and Remaining Problems

The primary problem areas in solar hot water technology are system costs, performance, and the durability of components and systems.

In both air and liquid circulating active heating systems, advances in technology are required to reduce installed costs and improve the perfor-

mance of the various systems used to heat and cool buildings. Additional problem areas are inadequate system installation, inefficient operation and improper system controls.

In solar cooling systems there is a need to reduce system and component installed costs while improving system performance. Related problems are improving system reliability, system design and operational practices and procedures.

Solar design proceduures are generally not widely available in the building industry. Thus, there is a need to develop such procedures for HVAC systems designers. Integration of solar design concepts should logically follow in order to strengthen the building code process as applied to solar energy systems.

Residential solar water heating systems are available at costs ranging from $2,000 to $4,000, and offer savings from 40 to 70 percent in annual hot water heating bills. Major packaged component subassemblies exist along with reasonably good sizing/performance estimating techniques.

Residential solar heating systems, both air and liquid, have been widely demonstrated in the field with varying degrees of success. Properly designed and installed systems have been shown to work well. However, active solar heating systems still suffer from high costs ($8,000 to $20,000) and are not competitive with fossil fuel systems. There is a need for packaged systems development and research directed at cost reduction.

In active solar cooling for both residential and commercial construction "thermally activated" absorption, Rankine and desiccant systems, are still in the development stage. Much of the work has focused on chiller development rather than on the system as a whole. Absorption and Rankine active solar cooling systems are currently the most advanced of these concepts. They have demonstrated reasonable levels of performance in the laboratory, but do not yet prove economical in field test situations. They are only available on a custom order basis at a relatively high cost

(e.g., $25,000 to $40,000 for a residential-sized absorption system including collectors, storage, etc.). Solar driven desiccant systems have shown promise in the laboratory, but await further research before they can become competitive. Here again, packaged systems need development, along with a concerted effort to reduce installed costs and to develop strategies to integrate these systems with the building and its energy system.

Products or Results Required

- Development of packaged solar heating and cooling systems
- Development of solar-powered systems, components and design procedures for commercial buildings
- System integration with the building as a whole
- Research directed at reducing installed costs
- Information dissemination.

Methodology -- Most Effective Way to Accomplish Objectives

- Develop system cost/performance goals and subsystem/ component level requirements necessary to meet these goals.
- Perform systems analyses for candidate heating and cooling system configuration.
- Rank system configurations in accordance with cost/performance goals. Identify potential target areas for cost reduction.
- Establish research and development plans for development of the highest ranking system configurations and their components, identifying research gaps and plans to fill these gaps.
- Develop and test prototype systems and components.
- Fabricate and test engineering prototypes.
- Disseminate information through industry involvement.

HEAT TRANSFER PHENOMENA

Objectives

To conduct experimental studies to gain an understanding of fundamental heat transfer phenomena, including: dynamic earth heat transfer (basement and slab), dynamic moisture heat transfer and storage, convective air exchange between zones, and air convection effects within low density loose-fill ceiling insulation.

Importance to the Building Industry

An improved understanding of these heat transfer effects would provide a basis for accurate and credible energy design calculations by engineers, architects, and building designers. These would allow for the evaluation of various design options to reduce the total system energy consumption.

Urgency

The lack of credible performance information - including the ability to predict expected performance of energy features - is the largest single barrier in the way of energy efficient building features (including solar options) being adopted on a wide scale.

Stage of Completion and Remaining Problems

Some very basic heat transfer mechanisms in houses are still not well understood. Basement and slab heat losses, because of the long time periods involved for measurements, have not been well characterized, yet have a large impact on annual heating requirements. During summer months, large amounts of outdoor moisture are introduced to the living space and absorbed by the interior construction materials and furnishings. When the living space is later cooled by the air conditioning system, this moisture is desorbed, increasing the latent load on the cooling system by as much as

100 percent until the moisture is removed. Room-to-room convective heat transfer is important for designing effective heat distribution in passive solar and area heating systems. It is also important for determining indoor pollutant distribution and in characterizing the heat load reduction potential through zoning. There is a strong need to measure these air convection coefficients as a function of room configuration and temperature difference. Several recent studies indicate that air convection within low-density loose fill ceiling insulation may reduce the thermal resistance by a factor of 2 or 3. These effects need to be quantified and mitigation strategies developed.

Products or Results Required

Heat transfer research would provide architects and engineers with accurate equations and usable design tools for builders, describing these heat transfer phenomena in real buildings. Data bases would be developed which could validate models developed by others.

Methodology -- Most Effective Way to Accomplish Objectives

Mathematical models would be developed for predicting these heat transfer phenomena. Laboratory and field experiments would be conducted to measure these effects in actual buildings under realistic conditions in order to validate the models.

PERFORMANCE INDICES

Objectives

To develop a generally acceptable, simple to understand set of energy performance indices to facilitate comparison shopping for homebuyers, marketing for builders, loan qualification for lenders.

Importance to the Building Industry

A set of well chosen performance indices (along with more familiar indices such as number of bedrooms, square feet of floor space, number of baths, etc.) could be a boon to profit-conscious builders by providing a marketing tool of recognized credibility. However, if such indices are developed, active involvement by the building industry is a prerequisite of success. Otherwise industry will tend to reflect them.

Urgency

Moderate reception by the industry would be united. Such indices are best developed in conjunction with voluntary performance quidelines developed by industry itself.

Stage of Completion and Remaining Problems

Energy efficiency in housing is a concept without a yardstick. The lack of a unified performance index (or a set thereof) may be one of the major barriers to the saleability of energy efficiency in the marketplace. Appraisers don't give much value to insulation, lenders often don't qualify buyers of efficient homes with marginal incomes, builders can't prove efficiency of their homes, and homebuyers are unable to assess operating cost for fuel of prospective homes.

To be meaningful, performance indices must be based on information which is credible to and easily verifiable by the building community. The development of such indices, therefore presupposes that computer models and other productive tools are validated using measured data and that a sufficiently large data base of reliable and verifiable performance data exist on building types of all kind to give the indices credibility.

Products or Results Required

A set of calculation tools (such as a point system) or simple measurement procedures to produce a performance index for new or existing houses. Such tools or measurements should be simple enough to be usable and understandable by builders, loan officers, and homeowners alike.

Methodology -- Most Effective Way to Accomplish Objectives

Currently existing computer programs are readily available to develop the simsplified point systems necessary for such a performance index. Pilot projects on such indices exist and can be examined. Measurement procedures (both long- and short-term) need to be adapted or developed to provide performance indices by direct measurement.

LONG-TERM NEEDS ASSESSMENT
ENERGY IN BUILDINGS RESEARCH

Objectives

Establishment and continuous refinements of long-term goals, objectives and priorities for an Energy in Buildings research program.

Importance to the Building Industry

A good understanding exists of many of today's possibilities for improved energy performance in buildings. Less well understood is the potential for improving energy performance in the long term. A better developed understanding could:

- Aid in prioritizing near-term research problems
- Provide motivation for continuing to improve performance
- Contribute to the development of long-term goals and objectives.
- Serve as a yardstick against which to measure program effectiveness and the relevance of research activities to real needs.

Accomplishment of the above could help maintain continuity of a research program, adding to the efficiency, cost-effectiveness, and overall success of such a program. In the long-term, more energy efficient buildings will occur sooner, saving the economy more energy and money.

Urgency

High - The most costly (most wasteful) feature of our national energy policy is its lack of long term consistency, stability and the absence of raional planning based on the assessment of real needs.

Stage of Completion and Remaining Problems

Much progress has been made in other countries. Some of their experience is applicable to the United States. There have been a number of promising domestic approaches as well. Also, most have been shelved. The greatest underlying problem is the politicization and ideiologization of energy policy. This has, for the most part, prevented the development and execution of long term energy planning, on the basis of solid facts, in the United States.

Products or Results Required

Research results would include images, examples, descriptions and concepts of energy applications that society would come to expect of its buildings in the future. Such buildings would:

- o Use energy more efficiently
- o Better serve the needs of the occupants (vis-a-vis energy)
- o Better utilize and interface with the natural environment (i.e., renewable energy)
- o Produce more energy, annually, then they use
- o Better interface with the National energy distribution system.

Examples include buildings that sense environmental conditions (both interior and exterior) and automatically adjust building elements (e.g., walls, windows, energy subsystems) to make optimal use of available energy to provide for occupant needs. For example, a wall under one set of conditions might admit light and exhaust heat; under another, convert light to electricity, and keep heat in; under another, provide fresh air, limit heat loss, and store electricity for later use.

Other examples include the following:

- Wall finishes to vary mean radiant temperature (e.g., electrically charged paints)
- Carpets with high thermal mass
- "Linseed oils" to increase thermal capacity of wood
- Reversible polarity of wall panels to radiate heat or cool
- Oxidation and reduction devices from chemical reactions for storable and transportable heat storage
- Structurally strong insulations
- Heat pipe-like building materials
- High R-value glazings
- Fiber optics for transferring natural light from outside to deep inside
- Paraffin-filled glazings (e.g., "cloud gel") for variable transmissivity and heat storage.

Methodology -- Most Effective Way to Accomplish Objectives

Convene a working group of 10 to 15 people. Support them with an advisory board representing the full range of industry constituencies.

Utilize available forecasting techniques, trend analysis, etc. and the considerable data bases available to industry and government on construction and population trends. Maximize interaction wise building research activities in other countries, fostering interaction on as many levels as possible. One mechanism to do this is the International Energy Agency. There are also bilateral arrangements with certain countries, and may many other avenues of exchange. Update annually.

RESIDENTIAL BUILDINGS -- MICROCLIMATE EFFECTS

Objectives

To improve the understanding of microclimate effects on the energy requirements of residential buildings. Develop strategies for enhancing such effects so that microclimate influences can be considered in the design of residences and the sizing of heating and cooling equipment.

Importance to the Building Industry

The majority of residential buildings across the country are not designed and constructed in harmony with their surrounding microclimate or other site-related features which affect efficient building energy use. Current zoning practice, in its setback and coverage requirements, does not take into account means by which the microclimate can best be utilized to reduce energy usage. Better understanding of the relationship between the microclimate, related site features, and residential building management by sensitive and knowledgeable users could result in significant energy savings and result in more livable residential environments.

Stage of Completion and Remaining Problems

The conventional formulas and tools used in the design of residences rely upon regional climate information. There can be great diversity of microclimates within such climate regions. The microclimate zone may be as small as the site of a few buildings or as large as an urban area. The factors creating the microclimate may be natural, such as insolation, prevailing wind patterns, nearness to trees and types of trees and local topography, lakes and rivers. The man-made factors may be built obstructions to wind paths and insolation, airborne pollutants that interfere with natural insolation, and heat "islands" created by thermal discharges into the environment. The problem is to better understand the nature and influences of these microclimates and how they can be modified.

Products or Results Required

- Develop inexpensive site-based climatological data collection and mapping systems
- Develop a published library of successful design and operation concepts consistent with microclimatic and site exceptions to regional climatic information
- Develop techniques for establishing microclimatic relationships and adjustments to existing regional data
- Develop techniques for identifying effective operation strategies from regular local weather forecasts and climatological patterns
- Monitored building performance data in the microclimate context.

Methodology -- Most Effective Way to Accomplish Objective

A systematic study of available microclimate information will help map the future course of research. This should be planned with industry and design professional participation since, by its nature, the research must be site specific and geographically disperse.

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DESIGN TOOLS

Objectives

Accurate building design tools provide the designer with the confidence that buildings designed for energy efficiency will perform as expected. The purpose of this effort is to provide the building industry with these tools and to ensure their technical accuracy.

Importance to the Building Industry

Clearly, energy has become a catalyst in the design of buildings. Now, more than ever, the design professions and building industry-at-large must closely cooperate on the issues of building design. The use of advanced passive and hybrid solar technologies, along with conservation techniques, large commercial, multi-family and industrial buildings will be accelerated if reliable design tools are continually developed.

Urgency

High. Design tools are the mechanism through which most other research results are implemented.

Stage of Completion and Remaining Problems

Federal programs and private industry have developed many new tools for addressing the problem of reducing energy use in buildings through innovative design.

Passive solar design tools have been developed rapidly during the past 6 years. However, only passive heating of residential buildings has available to it a full complement of design tools. At the same time, design tools for active and passive cooling and daylighting, and the inclusion of conservation techniques and other building types, particularly commercial buildings, have been inadequately developed.

A major shortcoming of the design tools produced by the applied energy research field during the past six years is the lack of conclusive performance validation. The majority of existing design tools have been developed and evaluated through simulations with existing computer models, which lack empirical evaluation. Currently available design tools remain to be evaluated and tested in a manner acceptable to industry and professional groups.

Also at issue is the completeness of the information documented by existing design tools. For instance, the developers of design tools have not properly accounted for the cooling impacts of passive heating systems. Design tools must accout for the total building of a system, not mostly for specific features.

Products and Results Required

The product resulting from this effort will be validated building design tools applicable to all users within the building industry. A complete package will include tools modified for micro/mini computers, complete documentation, and workshops for instruction in the use of these tools. Specifically, the following products should be considered:

- Provide simplified design tools useable by builders and retrofit contractors such as design rules of thumb, handbooks of typical construction details, and specifications. These should be made site-specific where necessary in order to address micro-climate effects and reduce the complexities inherent in the simplification process.

- Provide development and validation of the new generation of simplified energy analysis methods such as the multi-measure prediction tools (TC 4.7 bin method, cooling load temperature difference and cooling load factor methods, etc.). These techniques, when applied to micro-computer technology offer a way of examining energy issues at a much higher level than simple design rules without incurring the expense of detailed simulation programs (DOE.2, BLAST, etc.).

- Incorporate peer review into the release of these design tools to the building industry. Avenues already exist which have the support and confidence of the building trades in the presentation of new energy-related information (i.e., ASHRAE, AIA, NAHB, etc.).

- Provide a mechanism to present these tools to builders and designers in the form of workshops and appropriate journal publications.

- Consider the development and distribution of diskette based software through industry channels to builders and remodlers.

Methodology -- Most Effective Way to Accomplish Objective

Develop and find a design tool council with acting researcher/practicioner participation. This council should coordinate the assessment of research needs and develop a program to meet them.

PERFORMANCE PREDICTION

Objectives

To understand dynamic building energy performance through the use of comprehensive computer models, leading to useful design tools, including microprocessor based models, will provide the ability to generalize a limited data base to more situations.

Importance to the Building Industry

A comprehensive computer model would enable engineers and architects to examine design options and predict energy performance of buildings. It could predict the energy savings from retrofits and then assess their cost effectiveness. It would allow for equipment performance optimization. The ability to generalize existing field data to other situations would reduce the need for an unlimited data base on the energy performance of various design options.

Stage of Completion and Remaining Problems

Existing computer models are somewhat uneven in their treatment of the components of building energy use. Even the best dynamic building load simulation models are inadequate in the following areas:

- Dynamic ground heat transfer (basement and slab losses)
- Air infiltration prediction
- Dynamic latent heat storage and transfer (moisture)
- Room-to-room heat transfer including convective air exchange
- Interior furnishing effects
- HVAC system integration
- Consideration of the total building.

In addition, the models are highly user-sensitive. Many have not been adequately validated and give widely different results.

A comprehensive model must be developed which addresses these issues. In addition, the model must serve as a basis for usable design tools, such as a microprocessor-based simplified model, slide-rule calculator, or energy predictors for buildings.

To assess building systems performance, one would like actual performance data on various systems in many climates. Development of a data base of this magnitude is beyond the scope of any manageable project, and so a method to generalize actual experiments to other conditions is desirable. A comprehensive, verified computer model could generalize experimental results to other climates and configurations.

Other computer models will be developed because of special needs for detail or application. To validate these models, engineers need detailed weather and consumption data of actual houses in various locations. These would serve as a basis for gaining confidence in computer simulations.

Products or Results Required

The basic product of the research would be an improved understanding of dynamic building energy performance. The knowledge would be effectively accumulated in a comprehensive computer model able to simulate actual buildings and HVAC systems. Existing areas of weakness would be improved.

A data base of detailed consumption, temperature and weather data would be generated from many building systems and geographic locations to serve as a basis for model validation.

Ultimately, the model would serve as a basis for a simplified microprocessor based simulation model, a hand-held slide calculator to be used by builders to determine energy use, and general guidelines and rules for them for designers and builders.

Methodology -- Most Effective Way to Accomplish Objectives

First, mathematical models would be developed for the existing weak areas in building models. These would be integrated into a comprehensive computer simulation program. Detailed data would be generated from representative buildings to serve as a basis for model validations. Finally, the validated model would provide the ability to construct simplified microprocessor-based models, hand-held design slide calculators, rules of thumb and guidelines.

CONTROLS FOR RESIDENTIAL AND SMALL COMMERCIAL BUILDINGS

Objectives

To reduce energy use by increasing the credibility of information available to homeowners, building operators, and controls design professionals concerning the complex relationships which exist between HVAC systems, controls, maintenance practices and energy use in general.

Importance to the Building Industry

Due to present and projected fuels costs, the control of energy-using equipment, including HVAC and lighting systems, now assumes increasing importance. If controls systems are unreliable, if they do not conform to minimum standards of performance and commonality, and if their operating and maintenance requirements are not understood by design engineers, home owners and building operators, then the number of buildings operated in an energy inefficient manner will increase.

Stage of Completion and Remaining Problems

Homeowners often look on a thermostat as a throttle, pushing it to the highest setting when they want heat fast, pushing it to the lowest setting when they feel warm. Also, operation of the heating or cooling system while windows are open occurs frequently. Running the air conditioning system when outside conditions drop significantly below indoor comfort levels has also been found by many researchers.

Operators of small commercial buildings often lack the financial resources to provide full-time HVAC system operations and maintenance staff for their properties. For the same reason, they often do not retain competent design professionals when they are considering building controls purchases, maintenance and modifications. The prospective purchaser is faced with a large variety of competing "energy saving" devices and sys-

tems, and little or no objective, competent, professional advice or reference material to serve as a guide. There is, in essence, a significant and growing gap in the knowledge level about building controls between those who know these devices well and the preponderance of engineers and building operators who deal with these controls.

Building operators also often expect modern control devices and energy management systems (EMS) to be panaceas for a multitude of existing building problems. The point has been made repeatedly at ASHRAE and other professional forums that agressive building maintenance programs can lead to cost savings equivalent to those attained with EMS, but without the capital investment and with payback periods measured in weeks or months.

Further, little standardization exists throughout the building controls industry. Equipment produced by different manufacturers can seldom be interconnected without excessive difficulty, and software control programs are not transferable between manufacturers. While this may tend to serve the interests of major manufacturers, it acts against the interests of the far larger community of building operators, by limiting the equipment selection available to them, especially for system upgrading or expansion.

None of the foregoing problems is being addressed in any major or realistic manner at this time.

Finally, almost no validation of control strategies or real building EMS experience has been performed by objective organizations. Building operators do not trust computer simulations or controls manufacturers' claims concerning energy cost savings. Actual operating experience, documented and analyzed by credible sources, is required if the more intelligent building operators are to invest substantially in energy management equipment.

Products or Results Required

- Residential controls that are more user-friendly, making it easier for homeowners to maintain comfortable (but not excessive) indoor conditions.

- Education and training to reduce the knowledge gap between the controls manufacturers and researchers, and those who specify, purchase, operate and maintain them.

- Consensus standards to assure adequate minimum levels of performance, reliability, and hardware and software interface compatibility.

- Guidelines to assist controls design professionals and building operators in specifying, purchasing, operating and maintaining building control devices and systems.

- Objective and credible analyses and validations of actual building control operating experience.

Methodology -- Most Effective Way to Accomplish Objective

- Develop voluntary consensus standards for control devices and systems. Promulgate these standards widely and revise them periodically as necessary.

- Develop credible building controls information packages concerning equipment selection, sizing, related building maintenance, expansion and retrofitting, and cross-manufacturer interfacing. Promulgate through respected communications channels (e.g., ASHRAE Journal; Heating, Refrigeration and Air-Conditioning News).

- Conduct training sessions and seminars for design consultants, analysts, building owners, and operators.

- Develop a series of building analyses to validate actual operating experience with a variety of control systems and devices (e.g., EMS, traditional controls, stand-alone black boxes).

RETROFIT ENVELOPE STRATEGIES

Objectives

The purpose of this research is to develop conservation and solar techniques applicable to the retrofitting or rehabilitation of existing buildings to improve energy efficiency with minimum negative impacts on operations and budgets.

Importance to the Building Industry

Modifications to existing buildings can include the addition of elements to the building envelope or major modifications to the building envelope when it becomes outmoded or deteriorated. Many residential and commercial buildings receive modifications of this type for non-energy reasons. Energy improvements to the building envelope can occur simultaneously if sufficient knowledge, motivation, products and methods exist, thus presenting a timely opportunity.

Advanced building envelope systems to improve the building thermodynamic response and to incorporate daylighting could reduce the energy requirements of existing buildings by an estimated one-third to one-half. In addition, it is likely that improvements in both thermal and visual comfort would be additional benefits resulting from the incorporation of these advanced envelope systems.

Products or Results Required

The product resulting from research in existing residential and commercial buildings is expected to be advanced building envelope systems capable of a dynamic response to changing climatic and occupancy conditions, which are integrated with the buildings' mechanical and lighting systems.

Methodology -- Most Effective Way to Accomplish Objective

- Develop an improved knowledge of building energy response in the residential and commercial sectors through investigations of existing building stock to identify areas of major impact.

- With active involvement by potential users (builders, designers, remodelers), develop concepts which integrate dynamic building envelope elements (including daylighting and thermodynamic integrity) with advances in building mechanical and lighting systems. The most promising concepts should be simulated to determine potential contributions; laboratory and field tests should be conducted; design tools and approaches should be developed.

- Work with designers, manufacturers, builders and user groups to ensure that new techniques are easily integrated with correct building practices and to achieve a high percentage implementation in existing buildings of acceptable research result.

RETROFIT EQUIPMENT STRATEGIES FOR RESIDENTIAL AND SMALL COMMERCIAL BUILDINGS

Objectives

Identify a menu of retrofit options and associated information/delivery mechanisms that will allow owners of existing buildings or other decision makers to select, with confidence, retrofit strategies appropriate to their needs. Retrofits to equipment, shell, appliances, solar subsystems, etc., need to be evaluated in a coordinated manner.

Importance to the Building Industry

If consumers or other decision makers, e.g., utility companies, had a mechanism to confidently select retrofit strategies to meet their needs at a known cost and with known reliability and energy savings; and if vendors could reliably demonstrate to a building owner the relative value of investing in their product, both would benefit and a major barrier to the use of more efficient equipment and lighting in existing buildings would be removed.

Stage of Completion and Remaining Problems

Huge potential energy savings are possible retrofitting building space-conditioning equipment, appliances, and lighting. However, individual building owners and other decision makers do not generally have available information to enable them to make large investments in such retrofits. Equipment and lighting retrofit options with the capability to address various user needs and building types, and tools to select menus of options for particular situations are needed. Since even with this capability there will be variations between predicted and actual retrofit savings, means must be developed to help select features with reliable cost

and energy savings estimates. The interaction between retrofit equipment and the building shell must be better understood to improve overall cost-effectiveness.

Products or Results Required

- o A selection of retrofit options.
- o Selection methodologies that take into account relative and combined costs and energy savings benefits for various user needs and building types, derived from field-validated performance data, collected under realistic user conditions.
- o Quality control mechanisms to ensure delivery of predicted energy savings, (e.g., uniform performance test standards; third-party rating, certification and labeling, and inspection/monitoring of retrofits).
- o Methods of compensating for unavoidable variations of individual installations from predicted energy savings, and for relieving vendors of liability for those deviations for which they can not be held responsible.

Methodology -- Most Effective Way to Accomplish Objectives

- o Analyze building sector to identify likely groupings of building/user retrofit needs pertaining to various retrofit options, (e.g., single-family, older, oil-heated, 2- or 3-story residential homes in the urban Northeast).
- o Identify alternative operating conditions, (e.g., no one at home during day).
- o Test performance of various retrofit equipment options to meet various needs and conditions and develop low-cost performance monitoring methods.
- o Identify quality control strategies for retrofit delivery over various aggregations of installations, i.e., although it may not be possible to reliably predict retrofit energy savings in particular buildings, it may be possible to do so over an aggregate number, e.g., 10, or 100, given that certain quality control strategies are employed.

PERFORMANCE MONITORING AND EVALUATION

Objectives

The objective of this effort is to uniformly and accurately monitor, collect and evaluate performance data from existing and future residential, and commercial building structures and their associated appliance stock, power, space heating, cooling and hot water systems. The result is expected to be comprehensive data which characterizes the cost/performance of various typical building structures and their respective appliance, power, hot water, space heating and cooling system complements. The resulting evaluation of performance will then be used to determine areas requiring further research and development, and assist in validation of prediction models and design tools for the design and construction of energy-efficient buildings, and to build user confidence in new technology ready to be marketed.

Importance to the Building Industry

The results of comparative analysis, performance monitoring and evaluation will be the basis for developing design tools for the building industry with which to build structures that optimize the use of conservation and renewable energy technologies. Results of this effort will also assist in the validation of predictive models and the development and verification analysis/simulation techniques against measured building performance data.

Comparative analysis of monitored systems highlights design errors or misconceptions to be rectified in future system generations. Comparative analysis also highlights the strengths of systems and allows an integrated approach to building and building systems' design and construction.

Performance monitoring will identify whether a particular system has met or exceeded its designed performance levels. Comparative analysis will show how one system fairs against another in resolving the same problem.

Several areas of concern to the building industry are well addressed by performance monitoring and evaluation:

- Components can be evaluated in a real-world context of whole buildings.
- Generally, these buildings would be occupied, but there may be exceptions (Burch's research on thermal storage at NBS, for example) where the initial evaluation occurs in the more tightly controlled environment of unoccupied buildings.
- Evaluations conducted in the context of designed experiments with matched controls, planned in advance, can carry credibility and thereby encourage market penetration.
- Evaluation can be designed to monitor energy savings over time, and thus address durability; monitoring the savings achieved 5 to 10 or even 20 years beyond the time of initial investment presents an intriguing but vital challenge to the research community.
- Evaluations can be designed to monitor side effects (positive and negative) associated with energy savings, including:
  - Improved or degraded comfort
  - Improved or degraded indoor air quality
  - Improved or degraded safety or fire hazard
  - Improved or degraded integrity of building materials (e.g., due to moisture transport effects)
- Evaluations can be designed to assist in the formulation of performance indices for smaller buildings analogous to the Btu/ft^2/year index for commercial buildings. Experience needs to be gained with respect to the many conventions of building use patterns, solar contribution, choice of energy unit, treatment of site electricity, etc., which must be agreed upon for residential building indices to become useful.

- Evaluations can be designed to clarify the range of occupant preferences and use patterns actually seen in the field to serve as points of departure for design.

- Evaluations can be designed to clarify cost/benefit data reliably in field settings.

- The evaluation process will encourage the development of diagnostic instrumentation to measure building or component performance on the spot, which will be of broad utility both to design professionals and to occupants. The latter stand to benefit when diagnostics monitor the real-time performance of their building and its components (e.g. a gauge which gives energy use in some understandable units a gauge which monitors air quality). Information of this kind not only makes buildings more comprehensible but also serves as helpful feedback when changes are undertaken.

- The importance of energy-related investments in buildings can be clarified for energy policy analysts in the energy industries, in government, etc., as cost/benefit information is developed. Here a higher level of averaging is adequate but the need is much better met if there is geographically representative sampling, such as characterizes EIA's Residential Energy Consumption Survey (RECS). There is particular leverage to be gained when field performance data acquisition can piggyback on national statistical samples of this kind.

Urgency

Most urgent on performance monitoring depends on the credibility of practically all results of other research. Without it, little reaches the implementation stage - no matter how promising.

Stage of Completion and Remaining Problems

Building energy conservation and solar heating and cooling technologies are still relatively new. There is still a need to fully define and understand the dynamic performance characteristics of buildings and building systems, to measure costs and benefits under field conditions in a replicable way, to determine the durability of products and systems and the

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various positive and negative side effects which impact consumer acceptability, and to establish the actual occupant preference and use patterns which can improve the point of departure of design.

Products or Results Required

The product resulting from performance monitoring and evaluation of existing residential, commercial and industrial building structures and their respective systems complement is expected to be an integrated building system approach to design and construction. It is also the basic validation tool of all other research results.

Methodology -- Most Effective Way to Accomplish Objectives

- Develop a comprehensive building performance monitoring system utilizing or modifying existing performance monitoring system and evaluation methodologies.
- Develop standardized techniques and instrumentation approaches for collection of data which are rugged, inexpensive, and reliable. Look particularly for measurement strategies which address durability, side effects, and quality control generally.
- Develop a sampling strategy that is geographically representative, so as to serve the dual purpose of helping both the buildings professionals and the energy industry professionals as to the cost curve for conservation and the possible range of rates for market penetration. Use statistical designs in the measurement plan, including matched controls, wherever possible, to improve the cost-effectiveness of evaluations and reduce the ambiguity of conclusions.
- Collect, analyze, and coordinate the synthesis and publication of data on a wide variety of existing buildings and building components. Investigate all major building styles, vintages, and climates.
- Collect, analyze, and coordinate the synthesis publication of data on a wide variety of new building components in a wide variety of climates. Work with both occupied and unoccupied buildings, as appropriate
- Involve industry in all phases of this research.

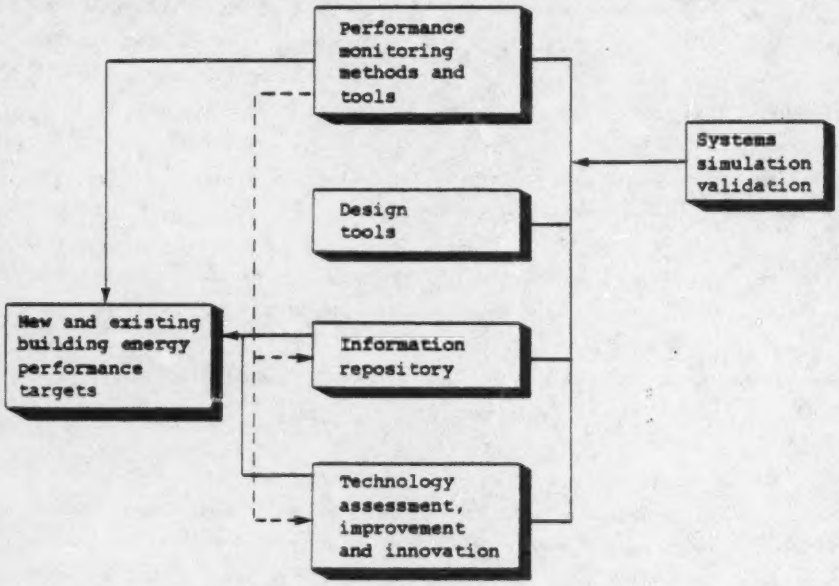
WHOLE BUILDING PERFORMANCE RESEARCH
PANEL IIb: COMMERCIAL OR LARGE BUILDINGS

The whole building performance group sees a need to assure that research efforts -- whether publicly or privately financed -- are directed toward development of technical and policy consensus about building energy performance targets. The continuing development of methods, validated conventions and analytical tools will contribute to establishing agreement about what it is reasonable to expect in the way of building energy performance, for both new and existing buildings.

A program of whole building energy research should integrate and interrelate the technical developments needed to arrive at consensus, and should reflect knowledge of actual building energy use and system and component performance. It should also create an opportunity to introduce improved and innovative technologies.

The community of interests concerned with the design, financing, management and construction of nonresidential buildings would benefit greatly from a national consensus on the technical potential for cost-effective energy efficiency improvements. Building owners and managers would have a basis for evaluation of current and planned facilities; engineers and architects would have a basis for comparison of design results; financial managers likewise would have a basis for comparison; and eventually means would emerge for rigorous testing of construction in progress.

The development of building performance targets is related to both technical developments and a process of continuing refinements in knowledge. The diagram below suggests some of the relationships between the areas discussed in subsequent pages and the overall aim.


Performance monitoring methods and tools
Systems simulation validation
Design tools
New and existing building energy performance targets
Information repository
Technology assessment, improvement and innovation

Industry accepted performance targets are necessary in order for architects, engineers, building owners and others to evaluate design concepts and redesign alternatives. Valuable information would be provided to building owners, managers, tenants, realtors, lenders and others, enabling building energy efficiency to be factored into their decision-making processes. As a result, a free market could begin to work in the interest of building energy efficiency. As guidelines, they would provide maximum flexibility, enabling designers to respond to unique site conditions and user needs. The inherent flexibility would also encourage and accommodate innovation in design approaches and building components and subsystems. Evaluation of whole building energy performance by designers would also steadily advance the state of the art in energy efficient

design, since the very act of estimating energy use improves our understanding of energy flows in buildings and sharpens design intuitions.

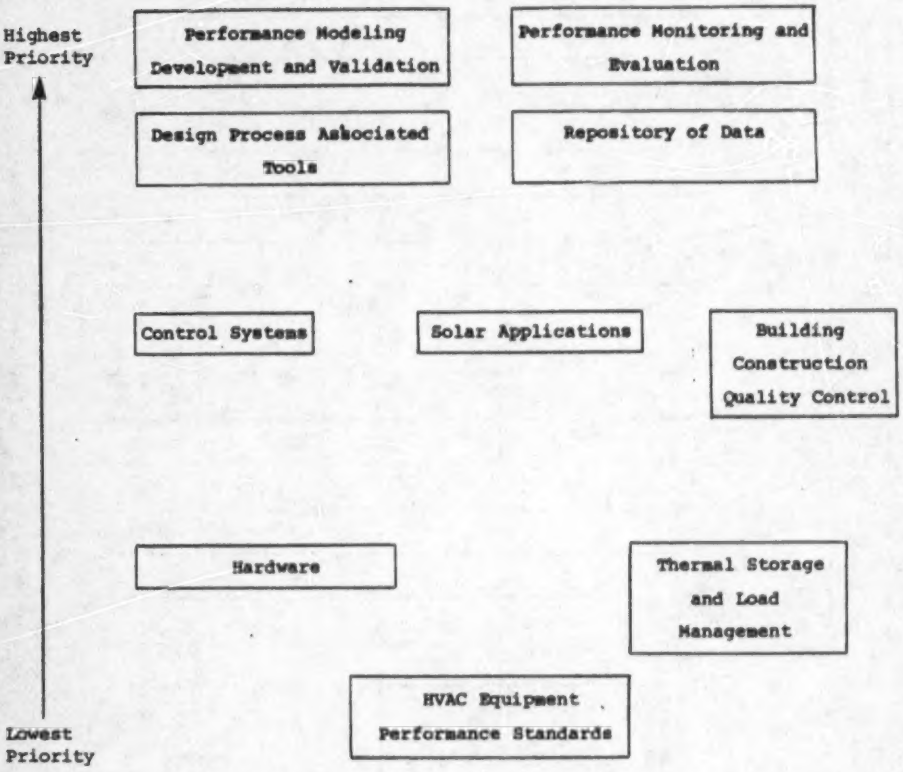
The following steps, addressed in whole or part by this workshop, need to be accomplished:

- Standard conditions must be agreed upon as a basis for both setting the performance targets and evaluating proposed designs or redesigns. These standard conditions include patterns of building operation for each building type and for each climate zone.
- Building types or categories must be agreed upon in order to publish and promote a finite number of performance targets.
- A format must be established for the performance targets that has widespread acceptance by the industry. This will include the resolution of the following types of questions:
  - Source versus property line energy use
  - Btu versus dollars
- Data on whole building energy use is not widely available in a form suitable for consideration in a consensus process nor do mechanisms exist to reach a consensus once the data are available.
- Building performance data and life cycle cost data should be generated or compiled suitable for use in a consensus process.
- A formal mechanism should be installed so that members of the building industry can reach consensus on standard conditions for evaluation, categories of building types and reasonable performance targets.

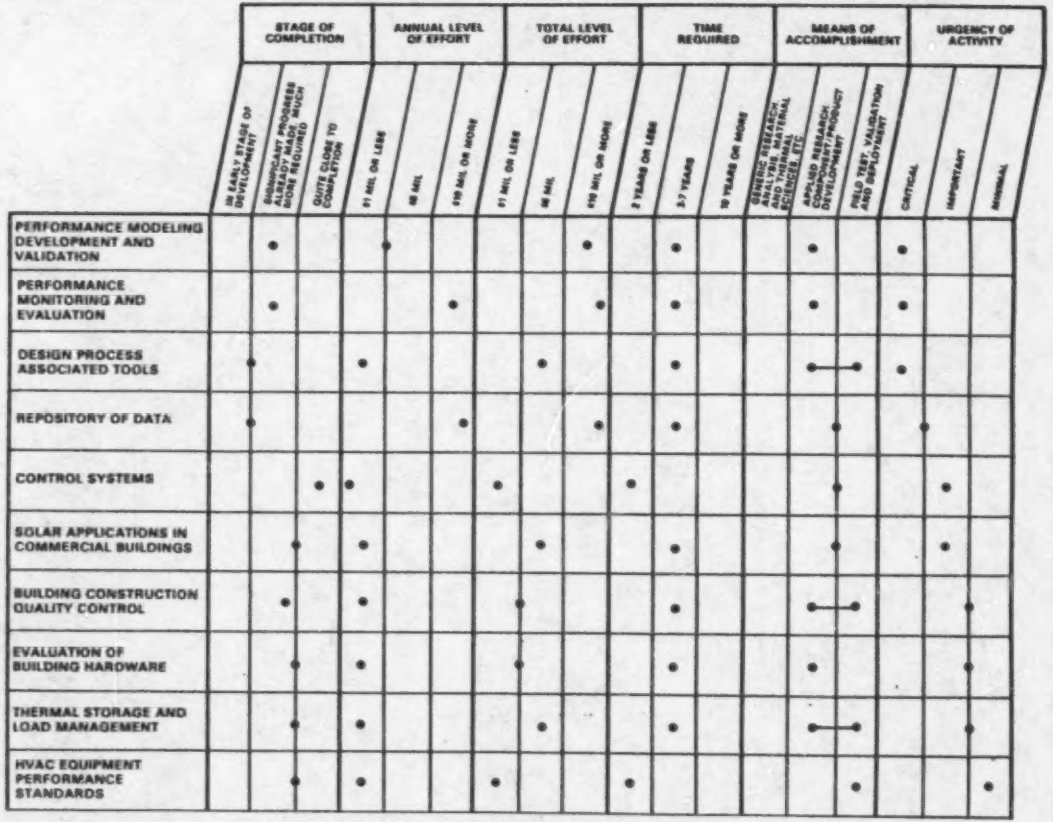
A polling of the whole building performance group established relative priorities for the selected research programs. The highest priority was given to "Performance Modeling" and Performance Monitoring. Both these programs were considered critical. There was consensus that a public domain computer program for simulation of commercial building energy flows must continue to be maintained and developed. There was also an agreement that the paucity of data on measured performance must be remedied.

Other high urgency programs were "Design Process Associated Tools" and Repository of Data". The universe of recommended programs and their relative priorities are presented in the following table. (The research papers are presented in order of program priority.)

PRIORITIZATION OF RESEARCH PROGRAMS



SUMMARY OF THE BUILDING ENERGY RESEARCH WORKSHOP



28 WHOLE BUILDING PERFORMANCE RESEARCH
COMMERCIAL OR LARGE BUILDINGS

PERFORMANCE MODELING DEVELOPMENT AND VALIDATION

Objectives

The objective of this task is to continue the development, maintenance, and validation of detailed, public domain, building energy simulation programs. This will be accomplished through the collection of two types of data:

1) Data on innovative components, systems and subsystems appropriate for developing new algorithms and subroutines for inclusion in the simulations

2) Use of this detailed data on whole-building subsystem and component performance for validation of these computer programs.

Importance to Building Industry

Building energy analysis simulation models can be used in a number of ways to increase the energy efficiency of new and existing buildings. These include:

- Calculating the thermal and luminous response of whole buildings to isolated or combined changes of the building skin, mechanical systems and equipment, controls, plant, and usage patterns.

- Identifying the major sources of energy usage in buildings so that high payoff areas for development of new materials, systems, and subsystems can be identified.

- Development and validation of simplified design tools, audit procedures, and rules of thumb through parametric modeling.

- Systems integration and optimization studies so that the most favorable combination of passive, active, lighting and conservation strategies may be applied to any given building in any given climate.

- Use directly as a design tool, especially for larger, more complex building types.
- Use by government planners to project the potential impacts of improvements in the building sector on national energy needs.
- Establishing building performance targets (energy budget goals).

In the past, the development of several public domain programs, including the DOE and BLAST models, have been supported by government. Although great progress has been made thus far, it should be realized that weaknesses exist in a number of areas, and that these weaknesses represent important gaps in our knowledge of building energy physics. It should also be recognized that to remain useful, these programs must be continually updated to stay abreast of innovations in the building energy fields.

Urgency

Highest priority item in this session.

Stage of Completion and Remaining Problems

Latest versions of DOE2 and BLAST (for example) are in need of continual update, including improved documentation and user support. A serious need exists for algorithm validation.

Product or Results Required

Updated, validated, well documented and user friendly versions of existing building energy analysis simulation programs with the capability of modeling all important building components, subsystems and conditions.

Level of Effort and Time Required

This should be a multi-year effort involving both the national labs and industry. Funding level should be approximately ten million dollars over the next five years.

Methodology -- Most Effective Way to Accomplish Objectives

To further develop, maintain, and validate public domain building energy analysis simulations, several activities need to be supported:

- Collection of laboratory data for developing algorithms and subroutines to characterize the behavior of new components, systems, and subsystems in a manner appropriate for inclusion in the simulations.
- Development and refinement of a validation methodology, including specification of data needs for applying the methodology.
- The collection of detailed whole-building performance data specifically appropriate for use with the validation methodology. These data would be archived and available to private domain model developers. If desired, professional technical societies could use the data and methodology to set industry quality control standards.
- Updating, debugging, and user services -- The extent of this activity would need to be worked out with industry consensus to avoid issues of "competition with industry."
- Development of new instrumentation where necessary for measuring important unknowns in the building measured heat balance equation.

PERFORMANCE MONITORING AND EVALUATION

Objectives

To measure and evaluate the performance of full-scale buildings, systems, subsystems and components to:

1) Determine the validity of analytical methods

2) Provide a basis of understanding of energy flow within a building

3) Develop performance factors and test procedures useful for standards and codes, including reliability, durability and life safety issues

4) Provide designers, builders and users with design guidelines and feedback on architectural and engineering solutions to building problems.

Importance to the Building Industry

The need is obvious. To date, extremely little high quality empirical data from actual buildings and systems are available to provide the basis of technical understanding of energy flow and system operation within a building. Without this knowledge base, the design community is unable to confidently design buildings and estimate energy consumption. This lack of knowledge has led and continues to lead to inappropriate design solutions and poor energy efficiency. Of all of the areas of building R&D, performance evaluation is the most difficult and costly to undertake and requires careful planning, implementation and continuous evaluation. It is the difficulty and cost factors which prevent the building industry from undertaking such an effort without government support, both technically and financially.

Urgency

Highest priority. This project is needed to provide data for validation of performance simulation models.

Stage of Completion and Remaining Problems

The proposed national program should be comprehensive and systematic. It should be organized into classifications by user information need categories:

Class A

Information for researchers primarily at the component level to determine thermal flow and heat transfer characterization, usually for model validation and conducted in a laboratory environment, including test cells and bench experiments.

Class B

Information for designers, builders, etc., of both new and existing buildings and systems to determine overall behavior and performance factors on site.

Class C

Non quantitative data dealing with institutional, occupant behavior and interaction issues, codes, standards and financial/marketability data.

The goal of such a program is to significantly increase the knowledge of energy-efficient design of new and existing buildings and to develop tested and reliable measurement techniques and performance factors.

- At the component level (Class A), the following areas should be explored, in order of priority:
  - Controls, sensors, instrumentation, logic and software
  - Diagnostic tools, measurement technologies and performance factors
  - Lighting systems (including daylighting)
  - Fan and air distribution, natural ventilation

- Stack effect
- Pumping (hydronic systems)
- Storage devices
- Heat recovery/exchanger and energy conservation
- Plant equipment (chillers, boilers, etc.)

o At the (Class B) system level:

- Building diagnostic tools and existing building strategies
- Mechanical (HVAC) system performance factors
- Atrium buildings
- Mass effects
- Climate
- Comfort
- Lighting and daylighting
- Peak load calculations and typical day analysis
- Part load efficiency

o At the (Class C) non-instrumented level:

- Operation and maintenance
- Occupant behavior and impact on system efficiency
- Institutional issues
- Financial/marketability
- Transfer mechanisms

Products or Results Required

o Performance factors (full-load and part-load) facility standards

o Design guidelines -- "lessons learned" and failure analysis

o Verification and improvement of design and analysis methods (i.e., manual and computer)

o Test procedures and input to consensus standards and codes

o New design approaches

o Saves fossil fuels

- Improved O&M procedures
- Improved construction techniques
- Knowledge base
- Higher quality buildings and lessening of liability insurance.

Level of Effort and Time Required

Minimum of 5 years and longer for certain issues. Cost is estimated at $10 million per year with participation by the government at 70 to 80 percent and by industry at 20 to 30 percent. The following division of funding is suggested as appropriate: National labs, 15 to 20 percent; universities, 10 to 15 percent, industry 40 to 50 percent, and other, 10 to 15 percent.

Methodology -- Most Effective Way to Accomplish Objectives

A joint industry and government program managed primarily by industry. Controlled by oversight committee composed of interagency/industry committee. The following basic steps are involved:

- Definition of information need
- Define performance factor and measurement technique
- Common reporting format
- Site selection criteria
- Instrumentation
- Monitoring (minimum 2 years per site)
- Analysis and evaluation
- Outputs -- reports, articles, handbooks, software/hardware, test procedures, etc.
- Project evaluation (annually)

DESIGN PROCESS ASSOCIATED TOOLS

Objectives

Design tools provide the vehicle by which known principles are applied to the design process to achieve an expected result. As such, they must have a known accuracy and be suitable in all respects to the design process in order to engender the confidence of the user.

A uniform method of determining need, supporting development, evaluating and supporting the implementation of energy related design tools is to be provided.

Importance to the Building Industry

Clearly, energy has become a substantial design criterion in buildings. Many owners, architects, engineers and builders have responded in various positive ways. Because of lack of design tools (i.e., a method for bringing the results of past knowledge and experience to bear on current problems), these efforts have often been less than what was possible.

Increasing the confidence level of the building community in the accuracy of tools will certainly spawn more bold and innovative activities in building design.

Substantially more energy will be saved simply by allowing the design professional to assure the owner with some confidence that expected results will be achieved.

A greater number of energy conscious designs will emerge simply because building designers, not particularly concerned by the energy issue, will feel less threatened by the apparent mystique which is currently surrounding energy design.

A standard evaluation/validation method will permit the industry to know what is available, for what purpose, at what level of accuracy, etc. Perhaps of equal importance will be the ability to recognize what is needed but not available to give a coherent and coordinated direction to further design tool development.

Urgency

High priority item (just below the two highest items), urgently requiring attention.

Stage of Completion and Remaining Problems

There is currently a plethora of so-called design tools in the literature. Little is known about their accuracy, appropriateness for use, cost, method of procurement, etc. Instead of being a wealth of resources for the designer, this situation has caused substantial confusion, suspicion (due to unsupported claims) and resistance to use by the design community.

There is not a clear distinction between analytical tools and design tools. Most tools available tend to be analytical in nature. They were developed for use in an analytical process and were developed by people who never design buildings. The distinction will never be absolutely clear as it is possible to use analytical tools as design tools by those thoroughly familiar with the tool. The major distinction is one of process, not mathematical form. In general, however: 1) Analytical tools assist the professional to calculate the effects of what he has done, and 2) design tools assist the professional in making decisions about what he should do.

- There is no conclusive performance validation on most existing design tools.
- There is no uniform evaluation method to compare existing or future design tools.

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- There is no technical body providing peer review of design (or analytical) tool development.
- Existing tools do not generally reflect an understanding of the needs of the building designer when engaged in the building design process.
- There are numerous aspects of whole building energy performance which are influenced by design decisions but are not adequately accounted for in most design tools.
- There are many component-based design tools, such as duct calculators, shading diagrams, etc., which have been in successful use in the building industry for some time.

Products or Results Required

- Validated design tools applicable to various uses in the building industry, hopefully fewer in number than at present but with a much higher confidence level.
- An established evaluation procedure for whole-building design tools.
- An organization for peer review for technical competency and industry need (potentially the Building Design Tool Development Council presently in existence).

Level of Effort and Time Required

Five million dollars over a five year period.

Methodology -- Most Effective Way to Accomplish Objective

1) Establish evaluation procedures including validation. Validation against standard data packages developed from validated simulation models is recommended. Validation against measured data will be inadequate due to the synthesis involved in most design tools.

2) Evaluate and validate existing material. Screening by survey and then validation will probably be necessary due to the large number and duplicious nature of many of the existing tools.

3) Publish results and indicate those tools, handbooks and codes which are inferior, inaccurate or redundant.

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4) Establish the needs of the actors in the building industry for various forms of energy information in their particular process. Also determine the adjunct criteria for design tools (i.e., cost, time to learn, time to use, flexibility, transparency, ease of access, hardware requirements, etc.).

5) Identify those existing tools which generally comply with the requisites of Item 4.

6) Now, develop those additional tools which are shown to be needed. Investigation of the use of large simulation models through parametric analysis to develop correlation which can be condensed to a computer-synthesized design tool should be undertaken. This is similar to the process used in the development of the SLR method and F-chart, two of the more useful design tools associated with solar energy system design.

7) Institute a process and the necessary requisites for peer review.

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REPOSITORY OF DATA

Objectives

To provide an efficient and effective network whereby established and emerging information on all aspects of energy-related uses and savings regarding buildings can be brought to the attention and made available to all segments of the professional, academic, public and user spheres and further to encourage and support programs of education based upon the preceding flow of data that would aggressively introduce the best and most useful of this data to specific users through six regional centers located in climatic sympathetic geographic areas.

Importance to Building Industry

Because of the highly fragmented nature of the building industry, no efficient system presently exists whereby industry participants (designers, owners, and policy makers) can draw upon a common pool of information allowing them to optimize their individual efforts of producing more energy-efficient buildings. A "user friendly" network of data would attract users distrustful or uninformed of more esoteric data banks.

For example, data on design energy budgets are needed in order to speak meaningfully about energy performance targets. Data on the energy use of building components, building subsystems and whole buildings are needed to establish the reliability of predictive models. To meet these needs, the data must:

- Meet an acceptable level of reliability
- Provide information at a level of disaggregation by building type, climate, and other parameter consistent with the designers' needs
- Be easily accessible and at an acceptable cost
- Be maintained and updated so as to be current.

Urgency

The question of national information sharing has been the subject of concern and effort for some time. Many sources of data exist, including published literature from the many professional societies and agencies, private and governmental sources, manufacturers and user groups. Among the most visible of these are ASHRAE, NTIS, the Department of Commerce and numerous industry groups, i.e., GRI, SERI, NAHB, etc.

None of these organizations functions through anything approaching a general clearinghouse, much less a central clearinghouse.

The net consequence is that much work and valuable information does not reach those who would benefit by the data. Only the most astute researcher is able to identify all (most) of the centers of information. As a consequence, large amounts of data are put to ineffective use due to inadequate channels of exposure. This represents a serious waste of research dollars and a substantial reduction of potential energy savings. Perhaps as much as 50 percent of all the first year potential is lost and as much as 15 percent of the full potential is never realized because it fails to reach ultimate users.

The small-scale non-integrated nature of the building industry effectively precludes most of the valuable data and information from reaching those industry forces who could put it to best and fastest use. The result is a serious time lag that often delays by years the application of new resources capable of effecting substantial and immediate energy savings.

There is thus an urgent need to establish an effective collection network, a system of classification and assessment, the establishment of a distribution clearinghouse and a system of critical feedback.

Stage of Completion and Remaining Problems

A large amount of data is being produced on the energy design features and energy performance of commercial buildings. The data are being pro-

duced by private architects and engineers, nonprofit building research organizations, Federal, state and local government programs, university researchers and others. Although a wealth of data exists, it has not been collected, orgainzed, screened, and analyzed in a rigorous manner. As a result, much of the data are of limited usefulness.

A great deal of information flow is along paths of traditional design or user concern based on traditional restraints of building codes, placement economics, life safety or user facility.

No successful effort has been achieved in effecting a clearinghouse of energy saving data. In some circles the DOE has been identified as the designated information center but more than $300 million has been spent in the last year or so by all federal agencies for energy-related information distribution without any central authority to validate its likely usefulness.

A single bureau must be identified or created to work within a controlled, voluntary consensus approach of data assessment.

Product or Results Required

- o A national network of sources funneling all energy saving data (related to buildings) through a system of identification, collection, assessment and distribution to all classes of users. The more quickly this is accomplished, the more useful/beneficial energy savings will result in terms of time lag reduction.
- o Periodic reports of the information compiled in the data basis within the repository, disaggregated into subsets useful to the building industry and others.
- o Regular analyses of the problems encountered in the development and maintenance of the data bases and their resolution.

Level of Effort and Time Required

By its nature, technology transfer must be an on-going activity. In the first 3 years and annual expenditure rate of $30 million is forced by a

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start up and collection cycle necessitated by the present absence of any central clearinghouse. A gradual decline over years 3 through 7 to an annual rate of $12 million results from the increasing effectiveness of the free flow system and a decline in capital start-up expense after the first phase of collection. After years 7, continuing costs will be a factor of inflation rate and the amount of continuing new data generated.

In the first 3 years, substantial effort is needed to create the network and collection system for all prior existing data/information. During the next 2 to 3 years the distribution network will require development, probably through the creation of regional centers.

It will be essential from years 3 forward that a positive active system of education be implemented.

Methodology -- Most Effective Way to Accomplish Objectives

Since this is a function of information collection, assessment and distribution, conventional aspects of research are not related. Research funds should absolutely not in any way be allocated, controlled or influenced by the organization established for information dissemination.

The critical difficulty in establishing a distribution network is the creation or identification of a centralized agency with responsibility not only to distribute but to collect and assess data without serious disruption or displacement of existing channels of information flow. The most practical probability is a screening panel of bureaus, academies, and research entities who would attach value to the incoming data, determine the data bases that would be established, and establish the information requirements for each entry into the data bases. The repository would publicize the creation of the data bases and would solicit data entries that would be required to be in compliance with the requirements established by the screening panel.

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CONTROL SYSTEMS

Objectives

Improve control system designs in order to reduce building energy use by optimizing energy management and control, by operating equipment at peak efficiencies, by using the most cost-effective strategies, and by delivering comfort and other environmental control amenities only where and when they are needed.

Importance to the Building Industry

In 1981, estimates of potential savings resulting from the use of optimal energy management and control systems in commercial buildings ranged from $150 to $360 per year per thousand square feet of floor space. While advanced controls would generally have a lesser impact in the residential sector, potential savings there can be substantial.

Due to present and projected fuel costs, the control of energy-using equipment, including HVAC and lighting systems, now assumes greater importance. If control systems are unreliable, if they do not conform to minimum standards of performance and commonality, and if their operating and maintenance requirements are not understood by design engineers and building operators, then the number of energy-efficient buildings will increase. Energy-inefficient buildings tend to become even more inefficient over the years as poorly maintained equipment degrades in performance.

Urgency

Important.

Stage of Completion and Remaining Problems

Close to completion. Additional work is needed in dynamic control system development and implementation.

Product or Results Required

- Education and training to reduce the knowledge gap between the controls designers and researchers and those who use and maintain them.
- Consensus standards to assure adequate minimum levels of performance, reliability, and interface compatibility.
- Energy conserving controls strategies encompassing HVAC, artificial lighting, and daylighting systems.

Level of Effort and Time Required

Estimated at $1 million or less over a 2-year time span.

Methodology -- Most Effective Way to Accomplish Objectives

- Applied research and field testing
- Develop and validate performance specifications for system components under realistic operating conditions (including effects of wind, rain, icing, dust, etc.)
- Develop and validate algorithms for total systems under realistic and dynamic operating conditions to provide optimal strategies for control of all major energy processes in buildings.
- Obtain consensus approval of standards.
- Conduct training sessions and seminars for designers, analysts, manufacturers, building owners, and operators.
- Develop "smart controllers" and control techniques to enhance comfort control in buildings.
- Characterize thermal comfort as a function of the measurable parameters that influence it in typical buildings.

SOLAR APPLICATIONS IN COMMERCIAL BUILDINGS

Objectives

To provide for the reduced consumption of non-renewable fuels and lower peak utility loads by increased use of solar energy.

Importance to the Building Industry

Solar energy has the potential to reduce energy consumption in nearly every category of energy use in the commercial building industry. Some examples might be:

- Domestic Hot Water -- already proven to be one of the most cost-effective applications of solar energy, the commercial building industry includes many building types with exceptional hot water requirements. While DHW requirements can be met with greater cost effectiveness by heat recovery techniques, this strategy is only available in buildings with substantial heat rejection. Hospitals, nursing homes, apartment buildings, dormitories, cafeterias, schools, laundries, and athletic facilities are all examples of potential beneficiaries.

- Space Heating -- While most commercial buildings are thought to have minimal heating loads, this is often true only during the occupied hours. Many commercial buildings have substantial night-time heating loads which can be offset by solar technologies. A particularly attractive solar application is to couple it with heat recovery chillers. During the day, solar is stored and at night is used to false load the chiller whose condenser water is used to heat the building.

- Space Cooling -- see discussion under "Problem."

- Dehumidification -- see discussion under "Problem."

- Electric Power -- the potential for integrated PV applications, such as:

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- PV/passive
- Peak shaving
- PV/on-site cogeneration
- PV/thermal coolant
- Dedicated off-grid systems.

to radically change the way we think of and design commercial buildings is enormous.

Urgency

Important.

Stage of Completion and Remaining Problems

The recent Solar Heating and Cooling Demonstration Program, resulting in the construction of approximately 215 commercial building solar systems, is virtually complete. It has produced a wealth of information, of which a substantial amount has been negative. A general result of the program has been that despite assurances and encouraging testimony from leaders in the solar industry, the industry was neither ready nor capable to undertake a major public demonstration. It soon became apparent that insufficient developmental work had been done, and commercialization was not "just around the corner." The heat pump industry had done precisely the same thing in the early 1960s and had to wait until the mid 1970s to recover. There are striking similarities between the two incidents and, unquestionably, active solar system commercialization has been retarded. The American character does not accept setbacks or failure easily and the unfortunate result has been a rapid retreat from active solar research and development. Few people have recognized the situation for what it was. It was fundamentally a failure in implementation and timing, not a failure of technical concept. Rarely in history has there been an opportunity such as this to specifically direct, as a result of actual experience, the course of future research.

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Passive solar applications in commercial buildings tend to be interwoven and at times indistinguishable from energy-conscious design strategies. Many elements of passive applications are covered under other research topics. The Passive Solar Commercial Buildings Demonstration Program currently under way is expected to give direction to future research needs in this area. The interactive behavior of passive techniques with total building performance is not well understood and architectural and engineering integration of these strategies is a general research need known to exist, but not yet adequately characterized.

Photovoltaic applications in commercial buildings portend many potential benefits, none of which has been adequately explored. There are presently some fundamental physical limitations which exist such as the electric energy density requirements of commercial buildings available surface area for P/V module deployment. This is such a multi-variable problem, however, that substantial additional research is needed. There is a major question concerning the cost effectiveness and technical propriety of distributed versus central PV systems which depends upon research for resolution. The use of PV systems on commercial buildings for a peak shaving alternative has never been investigated.*

Solar cooling applications have substantial attraction to the commercial building industry. Present vapor compression equipment operates with a top of approximately 3.0. Unfortunately, the heat actuated cooling cycles (absorption and Rankine) which are currently associated with solar systems operate at instantaneous COPs of 0.6 to 1.2 with seasonal efficiencies somewhat less depending on system design and application. Since

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* A common peak shaving or demand limiting strategy in commercial buildings is the reduction of chiller capacity. Since maximum cooling loads generally occur at times of maximum solar radiation, a PV system would be operating near maximum output and could be used instead of or in addition to the chiller control. As a result, peak demand would be referenced to a cloudy day cooling load instead of a full sun cooling load as is the current practice.

state-of-the-art solar thermal output costs $10 to $12 per 10^6 Btu and electricity is $15 to $20 per 10^6 Btu (typically), a 5:1 COP penalty is only offset by a 1:1.5 cost benefit, thus solar cooling is not currently cost effective. This, however, is a transient situation which may be mitigated by time, electrical energy costs and research. It also does not recognize the electric utility savings from reduction in peak demand.

The use of solar energy to drive a dehumidification system placed in series with a conventional cooling system has substantial potential. If the latent cooling load in a commercial building were to be removed by solar dehumidification, the conventional vapor compression machine would see only the sensible load which could be handled at much higher evaporator temperatures with an attendent increase in efficiency. No substantial research has yet been conducted in integrated solar dehumidification processes.

Products or Results Required

- Identification of the most technically appropriate and cost-effective solar strategies
- Identification of the most significant problems in design, construction and operation of various solar systems
- Identification of the most appropriate and reliable design tools
- Performance data from controlled experiments of innovative concepts
- Direction for future product development
- Cost reductions in existing solar systems
- Renewed public confidence in solar energy.

Level of Effort and Time Required

Five million dollars over a five year period.

Methodology -- Most Effective Way to Accomplish Objective

Utilize ongoing work being funded by research organizations (DOE, GRI, SERI, EPRI, etc.) to assess, develop and demonstrate promising technologies. Develop information on techniques to reduce cost, improve performance or efficiently design solar systems in commercial buildings. Utilize existing mechanisms such as professional society meetings, symposia and committees as well as trade journals, and research reports to discuss and disseminate this information.

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BUILDING CONSTRUCTION QUALITY CONTROL

Objectives

Rigorous evaluation of the sensitivity of predicted savings, from various components and systems, to the quality of the actual construction of those components and systems. In those areas of significant conservation limitation, the development of verifiable/consistent construction quality standards (such as insulation integrity, infiltration limitations), these standards would have to be tied to specific, standardized post-construction validation tests (building diagnostic techniques) which would be accepted by the construction industry to the point where they could be used as the basis for penalties or performance payments.

Additional evaluation of incentivizing methods such as performance payments, etc., would also be included to increase acceptance of these standards.

Importance to Building Industry

Industry studies indicate that poor insulation installation practice can result in significant loss of expected energy savings (e.g., less than 5 percent voids caused more than 40 percent loss in expected conservation). This hidden flaw in conservation action implementation can result in monies being spent on actions which, while theoretically attractive, are not cost-effective in the final analysis and which impact negatively on other interrelated energy systems and design assumptions (i.e., sizing the HVAC or solar system on the expected load).

Urgency

The Manchester Building, and similar real world experiences, indicates that significant amounts of potential energy savings are being "left on the

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table" through poor implementation of technically excellent conservation techniques. All new design and retrofit conservation actions are, to greater or lesser extent, circumvented by the quality of implementation. A quantification of this "results limitation" for various techniques is needed to allow realistic evaluation of technique and component potential during design and to guide additional research effort prioritization.

Stage of Completion and Remaining Problems

This effort is in the very early stages of review in NBS, DOE, GSA and Public Works Canada. The development of construction performance standards acceptable to the construction industry would require reproducable, accurately quantifiable building diagnostic techniques. Examples include: 1) expected infiltration rates which would be verified with a standard pressurization unit, and 2) expected overall envelope component "U" factors which would be verified by an integrating infrared scanning technique.

Products or Results Required

- Report quantifying construction quality impact on various techniques and component/system installation savings
- Development of performance standards and verification techniques
- Field test and validation, and identification of savings expectation limits for those techniques which can not be significantly improved
- Report on standards acceptance and implementation techniques.

Level of Effort and Time Required

For the initial implementation of industry acceptable construction performance standards and validation techniques -- $2 million and 3 to 7 years.

Methodology -- Most Effective Way to Accomplish Objectives

- Applied research, evaluating the construction quality constraints on specific techniques/areas of conservation design and quantifying the limitations of resulting savings
- Field test and validation of recommended improvements
- Evaluation and design guidance development which identifies techniques which are severely affected by lack of construction quality and can not be significantly improved
- Coordinated development of performance standards and validation techniques in those areas which can be improved.

Since the objective is generic and effects of construction quality result in significant broad based user impact, the effort should appropriately be supported by Federal resources. This effort would be an acceleration of on-going diagnostic work. An objective facilitating organization, such as the National Institute of Building Sciences, could effectively pull together an ad hoc coordinating council from the various affected sectors to provide R&D action elements with guidance on real world constraints and design process aspects. This group could also provide management direction for implementation of the developed standards.

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EVALUATION OF BUILDING HARDWARE

Objectives

Develop and implement a systems approach for evaluating the performance and cost effectiveness of hardware used in large buildings.

Importance to Building Industry

The energy savings and payback period of any improved building component must be determined considering the building subsystems in which it is installed and the actual conditions of operation. Component interactions have a substantial influence on building performance, energy use and life cycle costs. A systems approach for determining these effects requires modeling and field monitoring that is sensitive to component interactions.

The systems approach must handle the following components, systems and operating conditions.

- Ventilation
- Lighting (Including Windows)
- HVAC
- Walls, Roofs and Floors
- Controls (Including Energy Management Systems)
- Appliances
- Occupancy (or Use) Patterns
- Climate

Consistent evaluation procedures need to be developed in order to allow meaningful hardware performance predictions and data to be obtained.

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Urgency

Moderate. Purchasers, building owners, etc. do not have consistent, valid data on hardware performance. They cannot make intelligent purchase or construction decisions without this data.

Stage of Completion and Remaining Problems

Cost effectiveness and savings of retrofit hardware measures (as well as new construction) cannot be determined independent of the configuration and environment in which the hardware is installed. Claims for savings due to hardware installations are frequently made based on laboratory testing or simulations that do not include building component interactions.

Validated (industry accepted) performance prediction models and field test data gathering techniques are needed to consistently account for hardware, subsystem and operational interactions. Hardware characterization to be used in the modeling are required.

Product or Results Required

- A validated documented building energy use systems model for evaluating building hardware performance.
- A "catalogue" of hardware elements and their characteristics for input into the model.
- Extensive field test data on building performance with various hardware elements.
- Parametric evaluation of specific hardware elements specifying energy use and life cycle cost elements for typical building types, operating conditions and climates.

Level of Effort and Time Required

Two million dollars over five years in conjunction with the research on PERFORMANCE MODELING AND PERFORMANCE MONITORING AND EVALUATION.

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Methodology -- Most Effective Way to Accomplish Objective

- Identify and characterize pertinent hardware elements and conditions that require performance and cost evaluation.

- Select a building energy use system model to analyze the performance of the hardware elements. (Utilize one of the models studied in PERFORMANCE MODELING.) Increase the capability of the model, as required, to handle each type of building component.

- Obtain field test data on building energy use that includes an inventory of building components and log of the operating conditions and climate during the test period.

- Validate the building energy use systems model with the field test data.

- Document the model and make it available in a "user friendly" version for utilization by contractors, engineers, etc. in selecting cost effective, energy efficient, building hardware components.

- Parametrically evaluate the performance of hardware elements with the validated modeling using typical building configurations, operating conditions and climate. Make this evaluation (and the model documentation) available to potential users.

THERMAL STORAGE AND LOAD MANAGEMENT

Objectives

To shift building electrical demands to off-peak periods with benefits accruing to utilities in reduced generating and distribution costs and to building owners in reduced demand charges and energy costs (with time-of-use rates).

Importance to the Building Industry

The building industry must have proven cost effective techniques for reducing energy demand during peak periods in order to reduce electrical demand charges and to take maximum advantage of time-of-use rates.

Design strategies using ice and/or chilled water storage to shift cooling loads at the central plant are the most practical, but use of distributed storage devices should also be explored. Large central plants using heat pumps to recover heat from the building core are in use with multiple water tanks designed to store warm and cold water, but their designs could be inproved. Off-peak heating systems using storage devices with various storage media including phase change materials (PCM) need additional development. System designs using control plants to serve multiple load centers (separate HVAC systems in a large building or several buildings in a single complex) can be cost effective if the demand diversity provides a smoothed load that minimizes electrical demands on the serving utility.

Urgency

Moderate.

Stage of Completion

Off-peak heating, cooling and load management techniques are most effective in buildings with spike or impulse loads. Cooling and heating thermal storage system design methods usually employ manual methods, but computer simulations are available that gain system designer acceptance with only minor improvements.

Current PCM systems using ice are limited to smaller buildings with loads of about 100 tons or less, with water (sensible) storage systems usually utilized for larger loads. PCM systems using salts are generally in the experimental stage and need considerable additional development work to become practical.

Chilled water storage systems need additional research in improving anti-mixing methods (baffles, membranes, distributed jets, etc.) that will reduce tank sizes, simplify controls and lower construction costs. With ice systems, controls are needed for monitoring ice build-up rates with submerged tube refrigerant evaporators. Other ice making techniques, including winter snow generation, need further development.

Load shedding devices, through continuous monitoring of building demands, are currently available, therefore additional research is not needed. Field performance data from utility monitoring of existing ice and chilled water storage systems should be evaluated and documented with regard to their success or failure in achieving design predictions. A thermal storage system construction cost data base, compiled from existing installations, is needed to aid system designers.

Products Required

- Identification of the most practical and cost effective chilled water storage stratification methods.
- Recommended control strategies and techniques.

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- Up to date design tools including computer simulation programs, documentation of case studies, design manuals, construction cost data base and system controls.

Level of Effort and Time

A five million dollar budget over a five year period.

Methodology -- Most Effective Way to Accomplish Objective

- Establish laboratory procedures and conduct tests to resolve chilled water tank design issues and improve ice storage controls.
- Investigate and document the design, construction and performance of existing facilities using ice and/or chilled water storage systems.
- Enhance existing computer programs, field validate and prepare documentation manuals.
- Document the state-of-the-art in PCM salt storage systems. Identify applications that appear potentially cost effective and where possible recommend future research into media, component, controls, installation development.

HVAC EQUIPMENT PERFORMANCE STANDARDS

Objective

Provide a process for the development, maintenance and implementation of standards, based on performance over normal operating ranges, for HVAC equipment and subsystems.

Importance to the Building Industry

Solving most of the identified problems would give the industry greater capability to control the entire cost process from programming through operation. The results should be:

- o More predictable results from design to actual
- o Greater competition in both first cost and operating cost aspects
- o More accurate economic analysis due to increased confidence in the cost/performance relationship
- o An ability to use performance data rather than rating data in energy codes
- o An ability to use performance requirements as targets for industry in achieving equipment efficiency improvements (similar to automobile mileage targets).

Urgency

Moderate.

Stage of Completion and Remaining Problems

- o Performance data for HVAC equipment and some subsystems at the present time are available through the following sources:
  - ARI, Hydronics Institute, TEMA, AAMA, IBR and other similar industry-based institutions or associations
  - Manufacturers' catalog data

- The above sources of performance information have some of the following deficiencies:

  - Ratings, as offered by the institutions and associations, are usually based on one (or at best very few) set point of operating conditions and the testing is tightly controlled to hold all influencing variables steady (appropriate for a rating system but not useful for extracting performance information).

  - Ratings test results are often held suspect by the design professionals because of difficulty in duplicating results in the field.

  - Manufacturers' performance data are often given for extreme conditions only (sizing procedure).

  - Manufacturers' (and Institute) test procedures are rarely available in useful format.

  - Equipment selection by virtue of rank in a rating system is risky.

  - Inclusion of rating system information in energy codes as an indication of compliance is a weak method.

  - Using rating performance information in energy codes which are derivatives of industry consensus standards ensures mediocrity, eliminates competition and leaves the industry with no mechanism for sustained efforts in improving energy efficiency.

- In addition to problems relating to existing performance data sources, there are additional problems which stem from the simple lack of performance standards:

  - The energy use of components throughout their normal range of operations is not available to the design engineer for adequate evaluation.

  - Performance must be estimated by the designer by whatever means (variable) at his disposal and then procured for the owner by means of descriptive specifications (which are often broken by the manufacturer or contractor).

  - There are few (if any) legal mechanisms to ensure that an owner receives what he has contracted and paid for.

  - The presently increasing method of using system performance specifications for whole building systems when they can not be supplemented with individual component perfor-

mance standards has created extremely untenable situations with respect to collusion, cheating, professional, legal and financial liabilities.

- In recent years, the architectural and engineering professions have lost some capability to enforce their specifications and receive the system designed.

Products or Results Required

- o A process by which consistent and uniform testing of major HVAC components can be achieved
- o Performance standards and specifications which will stem from performance testing
- o Improved (in energy efficiency and enforcement capability) energy codes
- o Uniform part load performance data.

Level of Effort and Time Required

One million dollars over a two year period.

Methodology -- Most Effective Way to Accomplish Objective

Continue work with professional societies and trade associations in developing, maintaining and implementing standards.

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PANEL III

TECHNOLOGY TRANSFER AND DISINCENTIVES TO ENERGY EFFICIENCY

Background

The Federal government, through its R&D programs and regulatory activities, has been a significant part of the building community's efforts to design and construct more energy efficient buildings. Yet, in spite of the many millions of dollars that it has spent on the development of energy conservation and solar technologies for application in buildings, the federal government has never had a serious commitment to a technology transfer program that would assure the adoption of its R&D results by the building industry. Federal efforts to understand the legal, financial, and other institutional constraints that inhibit investment in the widespread use of energy efficient technologies have been fragmented. So many of the federal efforts have focused exclusively on the development of the technologies, with very little recognition of the traditional processes by which these materials, components, systems and design concepts are incorporated into the nation's buildings.

In the early years of the federal energy programs, the government appeared to believe that if it developed the technology, then it would be automatically adopted. However, in the past few years, some of the DOE programs had begun to make limited and fragmented efforts to assure that the technology and information that resulted from its efforts became known to the building community. Some technology transfer information and dissemination activities were very successful, others less so.

Aftermath of Current Federal Policies

However, the recent changes in federal energy policy has extinguished most demonstration, commercialization and targeted information dissemination activities. These programs are now driven by a policy of less federal government involvement in energy activities and a R&D policy that supports only long-term, high-risk, high payoff research, despite request for some

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flexibility by the building community. These policies have been applied with relentless vigor to buildings related aspects of the conservation program and to the passive solar program. All this has occurred without any examination of its appropriateness for the building industry's structure, which, by its nature, is decentralized and predominantly made up of small to medium sized firms, involved in building design, materials, systems and components development and production and building construction. This diversity and size make it very difficult for the industry to undertake a comprehensive research that focuses on the interaction of building elements. Thus, many building community organizations believe there still is a need for a strong, coordinated federal buildings energy research program that is based on an industry/government partnership.

In Partnership with the Building Industry

The concept of an industry/government partnership speaks to the need for continuous and stable R&D programs that are not subject to the whims of federal policy, but rather are based on the assumptions that energy efficiency in buildings is important to the Nation's economic wellbeing. It is also based on the premise that ongoing interaction between federal research activities and the building community is critical so that federal research meets both the long term and short term needs.

Other components of a partnership would include:

- ongoing review and evaluation of planning activities
- periodic review and evaluation of program activities
- industry directed technology transfer programs
- nontechnical research on disincentives to energy efficiency.

Along these lines, some industry experts suggest that the criteria established by the Congress in 1979 for the evaluation of DOE's Passive Solar Program still have merit for federal planning efforts. Those criteria are:

- o increased availability of materials, components and assemblies for passive solar design
- o increased awareness and application of passive systems by designers and builders
- o removal of institutional barriers represented by codes, standards, and the policies of lenders, insurers and regulators
- o the dissemination of information and the training of professionals
- o increased awareness by the general public of fundamentals in basic passive solar technology
- o sufficient technical, market and economic data to support a significant, ongoing research and development capability within the private sector.

Current Issues

To many, it appears today that there is no clearly defined technology transfer policy for building related research within DOE, despite the mandate of the Stevenson-Wydler Act passed during the 97th Congress. With the uncertainty that surrounds the future of these programs, many industry representatives believe that there should be a major emphasis on developing activities that would transfer existing R&D results to appropriate user groups, less much of this research be lost. This time DOE still seems unwilling to make a serious effort in this much neglected area.

In future R&D activities, the industry groups believe that technology and information activities must be an integral part of every research, project, and that all projects are planned to include appropriate transfer mechanisms so that the use of federal R&D efforts will be assured.

RECOMMENDATIONS: TECHNOLOGY TRANSFER

Background

The U.S. construction industry is far less successful than many other major industries in developing and adopting new technology. While there is no lack of capability in the nation to develop new construction technology, many times, building related research activities are uncoordinated. In many cases, they lack the necessary incentives and opportunities to commercialize and implement the results. This is true, even though studies have shown that there would be an attractive return on the research and development investment for new technology if it were broadly applied in the industry. In addition, little is done to communicate or transfer technology from one segment of the construction industry to another. However, even though diversity, fragmentation and institutional barriers are formidable problems, they have not inhibited the adoption of new technology when needs, transfer mechanisms and appropriate incentives have been recognized and used.

Transfer Mechanisms

Many transfer mechanisms currently exist in the building industry. Each is uniquely different and serves a different goal. These include:

Product and technology transfer, the transfer of promising products and technologies to that will promote the production, and use of these products and technologies.

Information dissemination, the transfer of beneficial research results to users to bring about change within these user groups.

Research transfer, the transfer of research documentation and data to users to bring about collaboration, new analysis, review and alternative use of the research.

Demonstration, the transfer of research results into a controlled environment to evaluate/validate its benefit to society and to realize its proof of concept.

Commercialization, the transfer of research results into the marketplace to bring about its acceptance and utilization in society.

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Barriers

Programmatic barriers exist which preclude the present effective transfer of energy research to appropriate building industry sectors. These include:

A lack of an institutionalized coordination process between the public/private sectors in the definition of research needs and objectives, and program planning and evaluation.

A lack of knowledge between the various public/private sectors of the research presently existing in the various sectors.

A lack of understand and utilization of existing transfer mechanisms for the various sectors.

A lack of research project planning for the transfer and utilization of the anticipated research results to specific target audiences.

Coordination of Private/Public Research Effort

Objective: To initiate and institutionalise a process of coordination between the private/public sectors.

Problems: There is a lack of an overall coordination between the public and private sector to define research needs and objectives, and to plan and evaluate programs.

Significance: At present, the process of obtaining private sector input for research program development and review is fragmented, ad hoc, uncoordinated between various components. This leads to a disjointed and criticized process. The amount of time and energy is neither effectively utilized nor channeled.

Solution: An overall coordinated process of decision and input points should be developed. Appropriate roles and responsibilities should be identified. The process should be well documented, ensuring appropriate representation from all involved and interested sectors.

Significance: This lack of understanding of existing transfer mechanisms leads to an ineffective final attempt at transfer and dissemination at the completion of the research.

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Solution: A coordinated plan should be developed which documents existing transfer mechanisms within various industry sectors to assist in developing specific transfer strategies for particular research results.

Urgency, Important

Incorporation of Transfer mechanisms into Research Programs

Objective: Initiate a process by which specific research projects incorporate well designed and understood transfer plans to effectively promote the desired effect of the research.

Problems: At present, most research projects are planned, proposed, and funded with regard to the ultimate transfer mechanism to be used. This leads to the development of final results and products that are not effectively transferrable and usable.

Significance: The inability to effectively and directly transfer and use research results reduces dramatically the return on the original expenditure of funds for the research. Without the direct transfer, research lies dormant and remains unused.

Solution: A procedure should be initiated to develop comprehensive transfer methods and plans as an integral part of each research project plan or proposal, including audience identification and input.

Urgency, Critical

SUMMARY OF THE BUILDING ENERGY RESEARCH WORKSHOP

	STAGE OF COMPLETION			ANNUAL LEVEL OF EFFORT			TOTAL LEVEL OF EFFORT			TIME REQUIRED			MEANS OF ACCOMPLISHMENT			URGENCY OF ACTIVITY		
	IN EARLY STAGE OF DEVELOPMENT	SUBSTANTIAL PROGRESS MUST BE MADE BEFORE IMPLEMENTATION	QUITE CLOSE TO IMPLEMENTATION	<1 MIL OR LESS	1-10 MIL	>10 MIL OR MORE	<1 MIL OR LESS	1-10 MIL	>10 MIL OR MORE	1 YEAR OR LESS	2-5 YEARS	5 YEARS OR MORE	DEMAND RESEARCH AND DATA NATIONAL SCOPE, ETC	DEMAND RESEARCH DEVELOPMENT	FIELD TEST, VALIDATION AND IMPLEMENTATION	CRITICAL	IMPORTANT	MINIMAL
TECHNOLOGY TRANSFER AND DETERRENTS TO ENERGY EFFICIENCY	•						•	•	•	•	•	•				•		
FORECASTING THE NATIONAL BUILDING STOCK		•		•			•				•					•		•
LEGAL CONSTRAINTS	•			•			•			•					•			•
BUILDING CODES AND PLANNING ORDINANCES		•		•				•			•	UNIFORM BUILDING CODE CRITERIA EDUCATION AND COOPERATION					•	
CONCENSUS STANDARDS		•		•				•			•	SURVEYS, CASE STUDIES, INFORMATION DISSEMINATION					•	
PRODUCT APPROVAL PROCESS	•				•			•		•				•		•		
VERIFICATION OF SAVINGS FROM ENERGY-EFFICIENT TECHNOLOGIES	•				•				•	•				•	•	•		
INFORMATION FOR SMALL BUILDING OWNERS AND OCCUPANTS OF SMALL BUILDINGS	•				•						•			•	•		•	
PERCEIVED RISK OF ENERGY EFFICIENCY INVESTMENTS FOR LARGE BLDG OWNERS	•			•			•			•		SURVEY AND INTERVIEW RESEARCH			•		•	
FINANCIAL INSTITUTION BARRIERS RESEARCH	•				•				•		•	INNOVATIVE FINANCIAL MECHANISMS DEVELOPMENT			•		•	
SPLIT INCENTIVES BETWEEN PURCHASERS AND USERS	•			•			•				•	SURVEY AND INTERVIEW RESEARCH					•	
EVALUATING TECHNIQUES FOR DELIVERY ENERGY EFFICIENCY TO BLDGS.		•	•					•			•	INNOVATIVE DELIVERY TECHNIQUES		•			•	
IMPROVING KNOWLEDGE OF BUILDING OWNER AND OCCUPANT DECISION MAKING		•		•			•				•	SURVEYS, RESEARCH ON PRICE RESPONSE		•			•	

3 INSTITUTIONAL & BEHAVIORAL DETERRENTS, TECHNOLOGY TRANSFER

FORECASTING THE NATIONAL BUILDING STOCK

Objective

A need exists to rationally forecast the likely future characteristics and composition of the building stock, which takes into account emerging technological, demographic, economic and social trends. Such forecasting is required for both government and industry to make informed decisions about research and other planning needs in the building sector.

Importance to the Building Industry

Such forecasting will allow adequate planning for developments outside the realm of events that building industry normally considers, which may profoundly affect the future of the industry. Failure to satisfactorily anticipate such developments may result in a succession of perceived crises to which the only possible response is short-term. Anticipation and management of such change offers the promise of harnessing such change to achieve a desireable future.

Urgency

It is extremely important to establish a history of survey and data collection and to expand the collection effort into more accurately forecast building trends. Anticipating building research programs is a key problem which transcends energy conservation in buildings. Clear definition of the building stock and its service to society is crucial.

Stage of Completion and Remaining Problems

Neither the public nor the private sectors has yet focused attention on national trends which may result in a future building stock radically different than that which may be extrapolated from past experience alone.

Such identifiable major trends as our transformation from an industrial to a service society, the internationalization of industry and irreversible increases in fossil fuel prices must be carefully scrutinized for their impact on the character of the future housing stock.

Demographic trends must also be ascertained and analyzed. While demographic change has long been recognized as a factor in predicting the volume of housing required by society, it has less often been analyzed to discern trends affecting the physical characteristics of the future housing stock.

Moreover, the direct and indirect (often, unanticipated) effects of developments in telematics, biotechnology and other new industries must be taken into account. Finally social changes and changing societal values must be examined for their anticipated impacts on the building stock.

Products or Results Required

The ultimate product of such an effort will be a continuous series of updated forecasts of building stock by market segment projected at various times in the future. It should be noted that forecasting is not prediction of the future. Forecasting, properly executed, provides a variety of future scenarios based upon available data and identified trends. Such forecasting provides a context in which short-term development may be better understood. The additional development of a "normative" forecast, one which delineates the most desireable confluence of identified trends allows planning of activities to achieve those outcomes.

Level of Effort and Time Required

Expanding survey and analysis initiatives is a collective problem that demands a committment from government and industry. Forecasting trends in demand for shelter and the characteristics of future housing and building will point the way toward opportunities for energy conscious design. The need is immediate and the effort must be sustained.

Methodology -- Most Effective Way to Accomplish Objectives

Such forecasts would be developed in a three-part process.

1) The first step is to solicit the predictions of selected industries about the technical and structural developments they foresee for themselves.

2) The second step is to aggregate this data across the selected industries and analyze it in the context of selected demographic, social and economic trends on both a domestic and world-wide basis. This analysis should result in the identification of overriding trends.

3) In the third step, the results of research would be presented to industry to allow its evaluation and utilization in their market planning.

Urgency, Important

LEGAL CONSTRAINTS

Objectives

Through the clarification of legal parameters contained in real estate practices, consensus standards, building codes, design and construction trade practices, unnecessary legal constraints that prevent use of new energy technology can be mitigated.

Importance to the Building Industry

The implementation of R&D results is hindered by impediments related to capital formation, manufacturing processes and marketing, standards enforcement, testing, certifications, inspections and performance warranties. Although new and innovative materials, techniques and approaches may be identified through basic R&D, legal factors may prevent the use or application of new products and information, in actual buildings.

Urgency

Legal and procedural impacts on production, design and construction practices have been increasing at rapid rates. Delays associated with compliance and legal protection are extreme. If new technology and new products are to be incorporated into the building process, these impacts and the risks associated with them must be rapidly reduced.

Stage of Completion and Remaining Problems

The building community is inherently fragmented and is characterized by numerous competing interests in R&D, product manufacturing, standards development, marketing, code development, and contracting practies.

Indicative of the free enterprise system in the United states, the building industry is subject to a multiplicity of regulations and laws

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designed to safeguard the public and protect private investments. Anti-trust laws set in place to assure open and fair trade practices have encouraged the establishment of product standards and agreements on minimum product performances. , Interstate commerce laws have resulted in barriers to some sectors of the building community in their attempts to produce and transport new equipment and supplies across state lines. Additional legal constraints exist in the areas of:

- o Design liability
- o Product liability
- o Tarriffs and trades
- o Code enforcement
- o Patent and copyright laws
- o Tax disincentives
- o Capital formation
- o Local zoning and subdivision restrictions
- o Real estate practices

Products or Results Required

Mechanisms need to be found to minimize legal constraints and the associated delays and costs. Systems should be devised to assure adequate protection of public health and safety without encumbering the introduction of new energy conserving technologies and products.

Methodology -- Most Effective Way to Accomplish Objectives

A broadly constituted investigation should be designed to explore the following areas simultaneously:

- o Investigation of cause and effect relationships with respect to legal barriers on energy standards development and use involving:

- Government standards
- Voluntary consensus standards
- Model codes and standards
- Industry standards
- Energy guidelines

o Identification of case studies where distinct energy technologies are restricted from commercialization by specific laws and regulations.

o Explore design and product liability issues with respect to the availability of new energy information and determine appropriate actions.

o Comparative analysis of foreign industry practices not subject to anti-trust, patent or trade restrictions.

o Analysis of existing relationships between foreign and domestic energy conservation standards for new and existing buildings.

o Reporting of measurable legal constraints to the Justice Department, the Congress, and the American Bar Association as well as interested corporate entities.

Urgency, Critical

BUILDING CODES AND PLANNING ORDINANCES

Objectives

To increase the probability of appropriate products from buildings energy research and development becoming adopted by standards-setting organizations and incorporated into building codes and planning ordinances.

Importance to the Building Industry

Building codes and standards are the benchmark from which most buildings are built. Codes and standards have traditionally been written and used to protect public health and safety. With building energy use being approximately 37 percent of total U. S. energy use, energy standards are becoming of greater importance. Compliance with the codes and standards is essential for architects and engineers to fulfill their responsibilities to the public as defined by state licensing and registration laws.

Urgency

National dependence on foreign oil supplies has underscored the need to conserve vast quantities of energy now used in buildings. One mechanism to accomplish rapid conservation efforts is through enforcement of energy conservation standards for buildings.

Stage of Completion and Remaining Problems

The Nation's building codes and standards are, for the most part, a product of private, non-profit code and standards-making bodies or industries standards established for non-compulsory use. Such groups are commonly referred to as standards-makers or model code groups. The use of energy conservation criteria and standards in building codes is recognized as being a public welfare issue despite the fact that it is not a public

health and safety concern. The distinction is important as compliance with energy standards insures durability and livability of the building stock but does not impact the health and safety of the general public.

The issue of Federal versus local standards-making activity has been debated in many national forums and in the Congress. There are several general problems with regard to the process for adopting energy codes and standards:

- Building code officials are accustomed to working with health and safety codes and not with energy standards.
- Energy standards are viewed as complex and non-essential.
- The process of incorporating research results into local codes is a slow process involving many series of reviews and to close scruting of code officials. Some local codes, conversely, refer to the "most recent edition" of technical standards, which may have been adopted by professional groups as accepted minimums -- but may not have considered costs and local conditions.
- With energy conservation has come much new technology but recognition by building code authorities and product approval groups has been very slow (i.e., heat pumps).
- Local officials are reluctant to accept and approve for use new technologies when they appear in a building's plan because they are not addressed by local code requirements.
- The three Model Code Groups are slow to adopt new energy efficiency standards and codes because their code change process is dominated by conservative, local building offices.
- The three Model Code Groups and the jurisdiction that retain code-making responsibility are often in conflict.

Products or Results Required

Clarification is needed on the relationship between energy standards and building codes. A national forum should be convened to address the proper use of energy technology in buildings with specific attention to the role of building codes as factors in the design process.

Methodology -- Most Effective Way to Accomplish Objectives

- Assess the building community's perception of energy conservation standards as a health and safety issue.

- Development of Manuals of Accepted Practice with on-going updates.

- Review of current codes and standards process to determine if streamlining is possible, and to consider "generic" energy performance standards with maximum flexibility so that designers can consider the full menu of energy-saving products, configurations and techniques.

- Development of training and educational devices for code officials, builders, architects and engineers to inform them about emerging products and new data.

- Code reviews of each new energy efficient product to ensure their timely fit into the code process (facilitated by seminars and conferences on new materials and product lines designed specifically for code officials).

- Identify potential incentives to accelerate the adoption of energy efficiency codes and standards by the private code-making bodies and states and local governments if building codes are determined to be proper vehicles for energy standards.

CONSENSUS STANDARDS

Objectives

To conduct research that will speed the development of appropriate consensus standards and minimize overlap and duplications among existing standards-setting bodies.

Importance to the Building Industry

The disparate sectors in private industry, public agencies at all levels of government, and the general public depend upon consensus standards as technical references to guide them in the manufacture, selection, installation, operations, and maintenance of materials components and systems incorporated in buildings. In the absence of scientifically based tests and measurement procedures, manufacturers cannot produce building materials at common reference levels; architects, engineers, and consumers have difficulty in making correct selections; and building code administrations are hard pressed to uniformly interpret state and local codes on a fair and equitable basis. In some instances, current test procedures have imposed high costs and lengthy procedural burdens on producers. Other standards have become obsolete as a result of technological advances.

Urgency, Important

Stage of Completion and Remaining Problems

Consensus standards are necessary to provide consistency among products and their manufacturing process as well as for the protection of public health and safety. Standards may become a barrier to the introduction and use of new energy technologies if the criteria are inaccurately applied or lacks a performance base.

Rapid technological advances in the development of energy-saving building materials, components and systems have out-paced current consensus standards. Technical data, which serves as the reference basis for consensus standards, are often insufficient for the broad range of diverse buildings in all climatic regions. Nevertheless, that data may be rigidly applied by those who administer standards. The result is the promotion of impediments to the introduction of alternative cost-saving building systems.

Technical data located in manuals and other professional guides published by societies or standards-making bodies offer guidance as to current and proven building practice. The advent (development and adoption) of consensus standards can have significant impact on the utilization of new energy saving devices and technologies. New information is often unavailable or inaccessible, slowing the consensus standards process and detering the consideration of revisions to existing standards.

Products or Results Required

The establishment of performance criteria for all existing energy conservation and equipment standards.

Level of Effort and Time Required

Certain performance standards already exist. Investigations should begin immediately to determine the performance base of current energy conservation and equipment standards. Performance models should be established prior to the development of any new consensus standards.

Methodology -- Most Effective Way to Accomplish Objectives

- Documentation of current consensus standards processes relative to energy conservation.
- Simplification of current test procedures in order to reduce cost and burdensome procedures without lowering technical quality.

- Definition of performance characteristics for existing consensus standards involving energy conservation and equipment.

- Generate performance models pertaining to new technologies prior to the understanding of consensus standards development.

PRODUCT APPROVAL PROCESS

Objectives

To rationalize the product approval process (testing and certification) for new energy-efficient technologies and to minimize the costs and time requirements for introducing new energy-efficient products and systems into the market place.

Importance to the Building Industry

Improvements in the product approval system could provide the industry with expeditious processing of new materials, components, and systems that could significantly reduce building costs and energy consumption. The spiraling costs of homes and commercial buildings could be checked with greater attention to project schedule and approve process. While no new innovation can be viewed as the panacea for major cost reductions, it is quite possible that the cumulative savings obtained through the introduction and use of many innovative products requiring approval could significantly decrease the costs of building construction and maintenance.

Urgency, Important

Stage of Completion and Remaining Problems

Present systems for evaluating building materials, components and systems against established technical criteria are very complex, time consuming, and costly. Many users are dependent upon the resulting certifications and validations for guidance in the acceptance of new products. These users include design professionals, builders, contractors, financiers, insurers, code officials, and building owners. The level of their understanding of technical findings may be very low, but their hesitancy in using new products is usually quite high.

Faced with the high risks that are characteristic of an industry that ranks second in the number of bankruptcies, users are generally reluctant to accept new products. The current product approval system is designed to assist designers, code officials and others by conducting the appropriate technical evaluations and providing evidence of product performance. The system is, however, believed to be cumbersome, costly and time consuming for producers seeking approvals and certifications.

Strengths and Weaknesses of Current Certification and Validation Processes

As currently practices, certification and validation processes in the United States have several strong points:

a. Openness--The processes are open to entry by a producer or importer at almost any point. He may select whatever level he deems appropriate and may approach any end user or authority having jurisdiction for use and acceptance. The effort required to secure acceptance varies by product, the authority having jurisdiction and the evidence presented for review.

b. Wide Acceptance of Validation--The major validating agencies' programs of design review, testing, quality assurance review and follow-up service are generally accepted by users and authorities having jurisdiction.

c. Acceptance of Engineering Reports--In the absence of a test standard for a new and innovative product, several major validating agencies will analyze the safety aspects of the product and produce an engineering report. These reports are generally accepted by authorities having jurisdiction.

d. Product Standards--The wide use of product standards for regulatory purposes provides for broad product acceptance. Voluntary standards in the United States are developed for a wide variety of useful purposes, only one of which is for referencing by regulatory documents. As a result, many voluntary standards contain provisions not appropriate for direct referencing in health and safety regulatory documents. Nonetheless, products certified to be made to recognized voluntary standards usually are accepted by regulatory authorities except when their regulations have specific validation requirements.

e. Large Number of Validating Agencies--A producer or importer has a relatively large number of validating agencies available to him. Many of these operate locally or regionally.

Several major weaknesses in the current processes also have been identified:

a. Definitions--Universally accepted definitions for terms commonly used in the practice of certification and validation are lacking. Indeed, in preparing this report it was deemed necessary to develop a glossary of important terms to avoid confusion. (See Glossary).

b. Excessive Testing and Levels of Validation--Validators and some project committee members alleged that, in some instances, regulatory authorities demand excessive and unwarranted testing and follow-up services. A review of applicable regulations does indeed indicate that some inconsistent requirements exist. An illustration will serve to clarify. Structural materials such as lumber (usually validated), steel (usually certified but not validated), and their fastenings (usually not validated) are commonly accepted by regulatory authorities; however, electrical construction materials, even minor associated materials, are required to undergo validation complete with follow-up services before acceptance by regulators.

c. Exclusion of Qualified Validating Agencies--In the area of electrical and plumbing products, the concern has been raised that the validation processes have not been open to all qualified validating agencies. Specifically, it was alleged that in the past the National Electrical Code effectively excluded many qualified laboratories from entering the electrical products validation field because it required the validating agency to be a "nationally recognized" entity. This language has now been changed to "qualified" and "acceptable to the authority having jurisdiction." A similar situation was alleged to exist in the validation of plumbing products for use under the International Association fo Plumbing and Mechanical Officials (IAPMO) Code which, in the past, accepted results from only one validating agency. Currently, results from several validating agencies are accepted by IAPMO but the feeling remains that there are many validating agencies with good qualifications that are not accepted. There are existing state and local building codes and regulations which contain similar restrictions.

d. Lack of Information About Capabilities of Validators--Of those surveyed, the smaller validating agencies that operate primarily on a local or regional basis have stated that they have much difficulty in securing acceptance from regulatory authorities where they are not known. Even the more widely recognized validating agencies at times have been denied acceptance by regulatory authorities. This is attributed primarily to the lack of any reliable listing or directory of validating agencies that indicates their level of competence and the fields of activity in which they engage. As noted in item "c" above, some regulatory authorities also are limited to validating agencies named in the laws and regulations that govern their activities.

e. Lack of Guidelines for Producers and Importers--There exists no comprehensive document that can lead a producer or importer through all the steps necessary to secure acceptance of his product by regulatory officials and end users. Some of the validating agencies studied in detail provide information on the steps and procedures necessary to secure validation from them, but this information does not cover the acceptance procedures that follow validation. Some organizations publish and make available their procedures for product recognition or approval. Although a comprehensive document is certainly desirable, its development would be difficult given the complex and varied nature of the certification and validation processes.

f. Lack of a Process for New Technology--Not all of the certification and validation practices reviewed include consistent, economical, well recognized procedures for the introduction into the building process of a new technology per se. The programs of the U. S. validating agencies studied in detail primarily address existing materials or products. New technology is involved primarily in the development of new products and materials and in the procedures used to evaluate and validate products and materials. However, as noted, new technology is considered important in the development of and in gaining acceptance for new products. Many products and materials introduced in recent years have gained acceptance by way of the model code organizations product recognition programs and other research, evaluation, and report programs, some of which are operated validating agencies. Those products and materials have been sponsored primarily by manufacturers and trade groups seeking formal acceptance of the products they represent by authorities in the jurisdictions in their proposed market area.

g. Lack of Consolidated Listing of Products--Each major validating agency maintains listings of products tested and accepted as meeting one or more identified standards. Many local and regional validating agencies, however, do not maintain such listings and the producer or importer must convince the regulatory authority that the validation is worthy. Some industry validation programs also publish listings of validated products and the pertinent standard. The model code orgainzations and CABO's NRB prepare and maintain listings of products, materials, and systems recognized to meet the provisions of the model codes. Few certified, but not validated, products are listed anywhere. Thus, a regulatory authority or end user that desires a reasonably comprehensive listing of validated products must maintain a library in excess of 30 volumes. Only major cities, the model code groups, and very large architectural and engineering offices can afford to acquire and maintain such an extensive single-purpose library, and there is no place for a small regulatory authority, end user, or professional to go to secure information on the certification status of a building material or product.

Generally, the certification and validation processes used in the construction industry work well in most applications. Progress in the industry is sufficient proof of this. However, significant improvements can be made to shorten the time required for acceptance of new and innovative products and technology without detriment to the existing processes. The strengths identified above will not be damaged or lessened if prudent measures are taken to correct the weaknesses.

If those weaknesses can be substantially corrected, the following benefits should accrue:

a. Necessary information on the capabilities of validators and on products and their validation will be more readily and efficiently available to regulatory authorities and other users.

b. Personnel of regulatory authorities and other users will be better equipped to cope with the expanding set of products and the standards used in their certification and validation.

c. Validators will receive due recognition and acceptance, which will enhance the use of distinctive certification marks.

d. Producers and importers will be able to plan for the acceptance of their products with prior knowledge of the type and level of validation necessary and to predetermine to which entities requests for acceptance should be directed to adequately serve the producer's and importer's proposed marketing scheme.

Products or Results Required

- Revisions of the product approval process to establish generic performance standards as alternatives to compliance with only one best method
- Identification of performance evaluation criteria and establishment of requirements and provisions for use as a basis for product acceptance in regulatory and procurement activities
- Development of standardized test and inspection methods for new energy-related building products
- Assessment of the potential product liability problems associated with a self-certification program
- Alternative patent processes and political/legal ramifications of modified patent practices.

Level of Effort and Time Required

A great deal of work has been accomplished on the subject of evaluating Product Approval and Technology Certification processes in the United States. Very little effort has been made to determine how this process may be altered to promote the use of more energy consious technologies and equipment.

Methodology -- Most Effective Way to Accomplish Objectives

- Review and assess the work already accomplished by the National Institute of Building Sciences, the National Bureau of Standards, the National Science Foundation, and others.

- Convene a series of broadly representative panels to determine the best avenues for effecting change within the current product approval processes, e.g., identify barriers with the existing infrastructure that can be eliminated.

- Identify a "straw-man" self-certification program and sample test a pilot, performance-based, testing and approval system.

- Determine the variations (potential and real) between current practices and the sample test -- include an assessment of performance variations from a life-safety standpoint.

- Promote a refined process to permit rapid introduction of building products with due consideration of the manufacturer's responsibility and liability.

- The effects of workmanship on the energy efficient performance of envelope components is of great significance. For example, it has been observed that improperly applied insulation in a ceiling can increase the heat transfer through the surface up to a factor of two, due to missing sections. It is apparent that the accepted practice of custom building residential buildings is a barrier to field achievement of the improved and innovative construction practices and techniques that implement construction measures. A possible change in practice would be to use factory built envelope components to be assembled in the field. The implementation of practice changes are primarily institutional barriers.

Proposed Action Plan

The perceived weaknesses in the certification and validation processes can be addressed by appropriate building community activities and should be based on the preliminary knowledge available through the National Institute of Building Sciences. To strengthen those features significantly:

1. A strong effort should be made to develop uniform definitions of terms. This is perceived to involve legal as well as technical matters.

2. A listing of validating agencies identifying their fields of expertise and providing some adequate measure of their competence in those fields should be developed.

3. The listing of validating agencies recommended in item 2 should be promoted widely. Especially important is acceptance by the model code organizations, major cities, states with statewide regulatory requirements, and the federal government.

4. A set of sets of guidelines should be prepared to aid procedures and importers in securing acceptance of products by the model code organizations, federal procurement and regulatory officials, and selected state and local regulatory authorities.

5. Develop methods for evaluating new building related technology to more adequately provide for the public health and safety, and to reduce economic loss.

6. The feasibility of establishing a central clearinghouse for information on all certified and validated building products should be examined.

Other actions have suggested themselves but research has been too limited to permit the recommendation of specific actions to correct all perceived weaknesses. To remedy this, an effort should be initiated to:

1. Determine and define the statutory, regulatory, legal, economic, and technical considerations, problems, and opportunities that exist in the certification and validation processes. Input should be secured from a large number of validating agencies including those that are local, regional, and specialized in their field. In like fashion, data should be secured from many procedures, regulatory authorities, owners, design professionals, and builders so that a comprehensive and accurate documentation of the processes may be prepared.

2. Analyze the information secured to determine the basis for certification and validation requirements and to assess the degree to which current practices meet those requirements.

3. Develop, test, and implement a system that addresses the requirements identified.

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INFORMATION FOR OWNERS AND OCCUPANTS OF SMALL BUILDINGS

Objectives

To accelerate the adoption of energy-efficient technologies and practices by owners and occupants of small buildings by making accurate information available through credible channels.

Importance to the Building Industry

The Office of Technology Assessment has found that less than one-third of economically justified energy-efficient improvements are likely to be made in this sector as a function of the market and current levels of government activity. Much of the remaining savings can be achieved by improving the quality of information. This is crucial to making the market operate efficiently.

Urgency

The importance of this item can be best communicated through mass-media (public and commercial television and radio). Far more immediate attention should be given to these "delivery mechanisms".

Stage of Completion and Remaining Problems

Although energy prices provide a motive for conservation, most householders and small business owners do not know what actions most effectively save energy, nor are they in a good position to monitor the effectiveness of their efforts. Complex information about the wide variety of energy-efficient technologies needs to be simplified to facilitate decision-making. Existing information is not easily comparable so that users can accurately assess the benefits of different options. Although most owners and occupants rely on energy bills to determine the effectiveness of energy improvements, price changes and complex rate structures confuse the con-

sumer and obscure this feedback information. And, finally, information does not get used unless it is provided by credible sources.

Products or Results Required

- Television and radio campaigns to improve energy efficiency in the home.
- Performance criteria for Voluntary Energy Rating System Development.

Level of Effort and Time Required

- Immediate benefits can be achieved by the publication and broad dissemination of rating system performance criteria developed by the National Institute of Building Sciences.

Methodology -- Most Effective Way to Accomplish Objectives

- Develop reliable methods for providing easily understood and comparable information which is useful to building owners and occupants in their decisions about the purchase and use of energy-efficient technologies.
  - Rating systems for buildings, appliances
  - Methods and devices to provide feedback to users about the effectiveness of technologies or practices including: restructured utility bills, feedback metering, etc.
- Test and evaluate the effectiveness of various channels and formats for providing information to users.
- Promote the distribution of credible energy conservation information for use by home owners. Retrofit information can be quickly and easily conveyed over public and commercial television.

PERCEIVED RISK OF ENERGY EFFICIENCY INVESTMENTS FOR LARGE BUILDING OWNERS

Objectives

To accelerate the implementation of energy conservation in buildings by identifying sources of perceived risk of energy efficiency investments and by identifying and developing ways of reducing actual and perceived risk.

Importance to the Building Industry

The perceived risk of energy efficiency investments is viewed as a very significant barrier to further investment by building owners. Reductions in perceived risk could lead some categories of building owners to relax their very strict payback criteria for energy investments and carry out cost-effective investments which represent sensible resource allocation. Little research attention has been devoted to assessing the relative risk of different energy investments and how that risk is perceived by building owners.

Urgency

An immediate assessment of cost/benefit/risk analysis methods is in order, with a view toward energy conservation and investment strategies.

Stage of Completion and Remaining Problems

Owners of large buildings make decisions to invest in energy efficiency improvements based not only on the expected payback in energy savings but also the perceived risk of the investment. Owners surveyed about their energy investment decisions continually cite a lack of reliable information as a reason for restricting their investments to those with

very fast paybacks (1 or 2 years). Owners also report concern about impacts of new energy-saving equipment on building maintenance and operating requirements. The narrow range of retrofits reported in surveys of actual retrofits is another indication that building owners are avoiding less familiar (and more risky) types of retrofits.

Products or Results Required

The effectiveness of this research depends on having a substantial body of data on actual savings from building retrofits and data on other aspects of such retrofits as reliability and maintenance and operating requirements.

Methodology -- Most Effective Way to Accomplish Objectives

The research should consist of:

- Understanding of the nature of the risk perceived by different categories of building owners of investing in new conservation and renewable technologies.
- Understanding of what constitutes information/knowledge adequate to alleviate high actual and perceived risk. This should include understanding of what are the sources of trusted information (such as journals, local civic groups, fellow building owners, etc.) for different categories of building owners.
- Incorporation of appropriate risk-reducing goals into the design of technologies and programs for different categories of building owners.

FINANCIAL INSTITUTIONAL BARRIERS RESEARCH

Objectives

Accelerate the implementation of energy conservation in buildings by identifying financial and institutional barriers for different categories of building owners to the efficient and effective implementation of energy-saving, energy-efficient, and cost-saving technology and developing institutional mechanisms and procedures to overcome the barriers.

Importance to the Building Industry

This research is very important because the benefit of technical research assumes that the research results will be implemented by persons and institutions consuming energy services. However, if financial institutions have procedures and requirements that prevent private sector firms from implementing cost-effective, energy-saving procedures and technologies, the potential benefit of the R&D will not be fully realized.

Stage of Completion and Remaining Problems

Many procedures and requirements of financial institutions delay or interfere with the private sector's efforts to buy and install energy-saving, energy-efficient and cost-saving technology. Many of these barriers have been identified but only limited progress has been made in developing alternative procedures and requirements for financial institutions that would allow or support the implementation of energy-saving technologies.

Methodology -- Most Effective Way to Accomplish Objectives

Working with financial institutions, develop:

- Innovative financing mechanisms (i.e., energy service companies, utility financing, tax-exempt financing, leasing joint venture financing) that would allow private sector capital to flow to cost-effective, energy-saving investments

- Change in procedures and requirements of standard financing institutions to make cost-effective, energy-saving investment opportunities more acceptable.

SPLIT INCENTIVES BETWEEN PURCHASERS AND USERS

Objectives

Increase the adoption of energy-efficient technologies by equipment and building purchasers who will not pay for the energy used.

Importance for the Building Industry

The split incentive problem probably affects more than half the energy used in the residential sector and half of the energy used by commercial buildings.

Stage of Completion and Remaining Problems

About one-third of U. S. housing units are rented, and more than half of commercial space is rented as well. Furthermore, approximately half of the energy used in residential buildings is used in appliances and HVAC equipment that is purchased by an agent who will never pay for the energy used by the equipment. In commercial buildings, the proportion is more than one-third.

When a builder or purchaser of energy-using equipment will not be the ultimate user of the building or equipment, there is an interest in minimizing first cost, choosing name brands of appliances, or, in some cases, choosing reliable equipment -- but interest in minimizing the energy operating costs of the building or equipment is only indirect. The users of the buildings and equipment, however, may be primarily interested in energy cost and have only an indirect interest in first cost and reliability. In these situations, signals from energy prices are not felt by building and equipment purchasers, and inefficient equipment with a long lifetime may be purchased as a result. There is some evidence that efficiencies of air conditioners purchased by developers for new homes decreased slightly over

the decade of the seventies, while average efficiencies of all other categories of air conditioners increased.

Methodology -- Most Effective Way to Accomplish Objectives

- o Assess factorrs in inhibiting energy-efficient investment in split-incentive markets
  - Appliance purchase decisions by builders and designers and sensitivity to energy prices
  - Barriers to investment in buildings in different markets
  - Effects of conversion to individual meters on energy efficient investments
- o Experiment with and evaluate programs to induce investment in energy-efficient technologies in split-incentive markets, such as:
  - Model agreements between owners and occupants to share capital cost and savings
  - Certification systems and other incentive systems for building owners to invest.

EVALUATING TECHNIQUES FOR DELIVERING ENERGY EFFICIENCY TO BUILDINGS

Objectives

Assist organizations such as utilities and local governments in designing effective programs to deliberately foster energy efficiency investments.

Importance to the Building Industry

This research is fairly significant. Conservation achieved by these programs is in the national interest; furthermore, decentralized efforts are more likely to be responsive to local conditions than comparable federal efforts. Only a few attempts have been made to evaluate energy efficiency delivery mechanisms. Improved understanding of what works and what does not -- in terms of savings achieved, customers attracted and satisfied, and program efficiency -- could help reassure utilities and local governments that such programs are feasible and prevent them from wasting resources on less effective programs.

Stage of Completion and Remaining Problems

Many utilities have identified energy efficiency investments and load management techniques as alternatives to further investment in central station power plants and have set specific conservation and load management objectives. Such efforts, however, require energy efficiency investments in a large proportion of the building stock in the utility area. To be effective, energy efficiency programs must attract thousands of customers and deliver energy efficient technologies using minimum resources. There are very few successful precedents for reaching large numbers of buildings in this way. Local governments may have similar objectives for different reasons (such as preserving the housing stock or assisting elderly citizens) and face similar program design problems.

Utilities and local governments lack resources to conduct research for developing effective techniques and comparing the effectiveness of different programs. They also lack the resources and incentive to inform other utilities and governments about the reasons for their successes and failures. Each activity must, therefore, organize without a basis in knowledge gained from other experiences; avoidable duplications of effort and program failures result.

Methodology -- Most Effective Way to Accomplish Objectives

- Design and evaluate different techniques of:
  - Streamlining audits
  - Incorporating user self-help
  - Attracting program participants in large numbers
  - Auditing so as to encourage retrofit
  - Attracting hard-to-reach categories of participants
  - Involving credible information sources in programs
- Design and evaluate different techniques of efficient and rapid installation of load management devices in commercial buildings, including:
  - Efficient and rapid installation of devices
  - Attracting customers to participate in a load management program
- Identify mechanisms for spreading knowledge of what works and what doesn't from one energy efficiency program to another; experiment with methods of spreading this knowledge.

IMPROVING KNOWLEDGE OF BUILDING OWNER AND OCCUPANT DECISION MAKING

Objectives

To develop basic knowledge of the ways different types of consumers respond to the combination of market conditions, technology design and delivery, energy information and government energy programs in order to improve product, program or policy design.

Importance to the Building Industry

This knowledge is important for anticipating the effects of policy initiatives and likely changes in market conditions on energy demand and on the level of consumer welfare. For example, the phenomenon of "behavioral backsliding" is of great concern to electric utilities who may be counting on decreased peak loads from conservation as an alternative to power plant construction. Analysis of consumer response to prices and programs is of concern to government officials who wish to evaluate the cost-effectiveness of programs or to project the effect on welfare payments of rising energy prices given the presence or absence of low-income weatherization programs. Some research has been done (especially by utilities) in evaluating conservation programs, but more is needed before the phenomena are really understood.

Stage of Completion and Remaining Problems

It is difficult to estimate in advance the effects on energy demand, physical changes in buildings or government programs because of the interactions of these and other forces. For example, when building retrofits are accomplished but fail to produce anticipated energy savings, it is not known whether the installation was defective, the physical analysis faulty, or there was "behavioral backsliding" of occupants who use energy less carefully or convert energy efficiency into increased comfort. Those who market retrofits or predict their effects are thus open to charges of fraud, incompetence, or misleading advertising.

Methodology -- Most Effective Way to Accomplish Objectives

- Evaluate, using both statistical and field evaluation techniques, the effects on energy use in buildings, singly and in interaction, of fuel prices, energy information, physical changes in buildings, and government programs. To what extent do building owners and occupants:

  - Increase energy-efficient investments?
  - Curtail energy?
  - Curtail other expenditures?

  How do these responses vary by class of owner and occupant? How does increased energy efficiency affect occupant behavior?

- Determine the effect of consumers' beliefs, misconceptions, attitudes, norms and values on their responses to energy price signals. Develop early indicators of secular changes in consumer preferences that may affect energy use independently of market events.

- Determine the extent to which energy efficiency is a consideration in purchase decisions about buildings, HVAC systems, and appliances. How is this affected by information and price?